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GENETIC CLASSIFICATION OF UNDERGROUND VOLATILE AGENTS.

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CONTENTS.

	PAGE.
The Problem	487
Individual Terms Already Suggested	489
Ground-water	489
Juvenile	489
Resurgent	491
Magmatic	492
Epigene and Meteoric	492
Vadose	494
Phreatic	494
Seepage	495
Connate	495
Older Classifications	496
Proposed Classification	498
Proposed Classification in Practice	501
Summary	502
References	503

THE PROBLEM.

Many changes in rocks and minerals below the earth's surface are controlled by the presence of subsurface waters, vapors, and gases—substances of highly varied composition, yet sharing the attribute of being volatile at relatively low temperatures and pressures. Of these fluids water is the most striking and, in the earth's crust as a whole, probably the most important. It is

never pure, but is regularly in mutual solution with other volatile compounds or with gaseous elements. Similarly, carbon dioxide or chlorine or any of the sulphur gases is seldom or never the only gaseous phase affecting a rock mass of even small volume. Complex and protean as these volatile associations may be, their components tend to act together in significant geological processes. In company they lower the fusion or solution temperatures of silicates. In company they cause gaseous tension in heated rocks. In company they help to direct the march of lithifaction, rock weathering, vein formation, or ore deposition. Because of the close cooperation of these fluids, the students of diagenesis, metamorphism, weathering, volcanology, plutonic rocks, vein formation, and ore deposits have generally no choice but to regard each concrete solution as a unit. Most of the solutions are chiefly composed of water; hence the name "waters" is commonly used to designate them, and that whether the water is liquid, vapor, or gas.

This figurative use of "waters" is likely to persist, since in most geological discussions it involves no obscurity of meaning. However, the principal volatile component of limestone or dolomite is not water, and it is a question whether the carbon dioxide doing geological work within the carbonate rock or, as an emanation, outside it, can be regarded as one of the crustal "waters" without stretching metaphor too far. There is needed a more appropriate term which shall signify not only well waters, spring waters, waters buried with sediments, the primitive water in live magma, the water of constitution or of solid solution in minerals, but also such magmatic constituents as chlorine, fluorine, the sulphur gases, the carbon gases, and the gases essential in calcite, sodalite, apatite, gypsum, etc., and the rocks containing these minerals. Neither "underground fluids" nor "underground solutions" is appropriate because magma is both a fluid and a solution. The expression "volatile substances" or *"volatile agents"* is less equivocal. The one word *"volatiles,"* employed as a noun, is suggested as a convenient, short equivalent. If "waters" were used in the same sense, its metaphorical char-

acter, as the whole named from a part, might be shown by always enclosing the word in quotation marks. That convention cannot be ultimately satisfactory.

Economic geologists, concerned with ore-bearing solutions, have been specially interested in the technical vocabulary required for a scientific classification of volatile agents. Yet it is manifestly advisable, if possible, to have developed a system of terms which shall be available for all kinds of geological specialists or for the general geologist. The purposes of this article are: to indicate how nearly the technical terms invented or adapted by the economic geologists fill the needs of the general geologist; on the other hand, to suggest to the student of ore deposits the value of certain inventions or technical adaptations of volcanologists and others; and to offer a general classification of underground volatile agents, founded on older classifications but somewhat more extended than any of these.

Unfortunately, most of the terms now commonly employed, though of modern origin, have not uniform definitions among authoritative writers, and it is essential, after reviewing sample variations of usage, to choose the definitions that are most warranted by custom and by the logic of a systematic scheme.

For bibliographic assistance the writer owes hearty thanks to his colleagues, Professors Graton and Lindgren.

INDIVIDUAL TERMS ALREADY SUGGESTED.

Ground-water.—While "ground-water" is a popular and engineering expression for seepage water at and below the water-table (the subsurface, so-called water-level) and is thus the equivalent of Daubrée's "phreatic water," some authors, like Kemp (1902, reprint, p. 2; 1906, p. 219), have definitely considered magmatic water as ground-water.

Juvenile.—Suess (1902, p. 141) introduced this word: "With the vadose waters of the earth's surface are associated new supplies (Mengen) which, reaching daylight for the first time and before our eyes, may be called *juvenile* waters." Again (1909, p. 630): "On the other hand, *juvenile* waters are those that

originate when hydrogen, emanating from the earth's interior under very high pressure and at very high temperature, combines with the oxygen of the atmosphere." There are obvious difficulties, of a quantitative nature, in the way of accepting Suess's speculation as to the manner in which juvenile hydrogen has been oxidized, and many geologists agree that the oxygen of primitive (magmatic) water is also largely juvenile. Chlorine, fluorine, sulphur, arsenic, and carbon are, according to Suess, other juvenile elements. He regarded the sea water, sea salts, and the atmosphere as all juvenile in the final analysis, as juvenile in former geological periods; but for practical purposes he grouped all these emanations of the past as "vadose" substances. Juvenile fluids are those in the act of appearing first at the earth's surface, or those of primary nature, arrested in the rocks on the way to the surface. Once delivered to atmosphere, river, or ocean, the emanations cease to be juvenile in a technical sense. In other words, Suess and his followers agree that proximate, rather than ultimate, origins should be emphasized in any useful classification. That view and the main principle of Suess's definition are reflected in the "juvenile" of the scheme to be proposed.

Gautier (1910, p. 437) and Clarke (1916, p. 213) use "virgin" as a synonym for "juvenile."

Though Suess attributed volcanic temperatures to the heat of primary hydrogen and other gases locally streaming out from the earth's interior, he nowhere states that all magmatic gas or vapor is directly of juvenile origin. On the contrary, a passage on page 655 of the third volume of "Das Antlitz der Erde," zweite Hälfte (1909), implies that he believed magmatic gas to be in part of meteoric origin. Nevertheless, a number of authors —including Lane (1908*a*, p. 502), Keilhack (1912, p. 73), Beyschlag, Vogt, and Krusch (1913, p. 135), Lawson (1914, p. 220), Pirsson (1915, p. 212), Leith and Mead (1915, p. 243), and Ries and Watson (1915, p. 594)—have used "magmatic" and "juvenile" as synonymous descriptions of emanations from magma. Spurr (1905, p. 256) writes of "magmatic or primitive

water"; Irving (1911, p. 668), of "'juvenile' or hot ascending waters." Ransome (1909, p. 198) is more nearly accordant with Suess and with the facts of nature in defining "juvenile" as "original magmatic." Kemp in 1908 (p. 706) recognized the possibility of magmatic gases other than juvenile, but in 1914 (reprint, p. 5) gave "magmatic" and "juvenile" as synonyms, thus aligning himself with the majority of the above-mentioned writers. This treatment of the two words is of course largely due to conscious or unconscious adhesion to a widely entertained speculation as to the origin of magmas, that they are composed entirely of primary matter.

Juvenile fluids may be: actually present in, or emanations from, hot or cooling rock-melts; in the fluid inclusions characterizing primary igneous minerals; in the gaseous components of some solid solutions; in the hydroxyl and other primary molecules chemically combined in primary crystallized rocks; or in emanations from re-heated igneous rocks. Thus, a juvenile fluid may belong to any one of Lincoln's (1907, p. 259) four classes of "emanations"—actual, fossil, repressed, and potential.

Resurgent.—"Resurgent" was adapted by the writer (1908, p. 48; 1910, p. 113; 1911, p. 57; 1914, p. 249) to signify the magmatic emanations of secondary origin, that is, those absorbed from country rock, either directly or during the solution of country rock in magma. Von Wolff (1914, p. 118) has accepted the word in the sense given and (p. 387) extends it to describe also certain pyroclastic deposits. As just noted, most authorities on the genesis of ore deposits appear to be opposed to the concept, and the very few authors who have seriously considered the origin of the ore-depositing solutions at or near igneous contacts generally regard "magmatic" and "juvenile" as of equivalent meaning. The sanction for the use of "resurgent" in the proposed classification is found in the many facts showing the reality of syntexis and profound endomorphic changes of primary magma. A great number of field observers have described such facts and they can no longer be explained away as the product of wild speculation. In any case, no geologist can afford

to ignore the possibility that resurgent gases have powerfully contributed to the development of ore deposits at igneous contacts.

Resurgent fluids naturally resemble the juvenile in their modes of occurrence, whether as constituents of live magma, as actual emanations, or as prisoners in frozen magma.

Magmatic.—The quantitative importance of secondary magmas is a matter of controversy, but no geologist with even minimum skill and experience in field interpretation doubts that locally sediments and schists have been absorbed by primary magma, which has therefore become charged with some resurgent volatile matter. Hence, in the interests of clear thinking, "magmatic waters" will here be held to include both "juvenile waters" and "resurgent waters"; more generally, "magmatic volatiles" (with "*hypogene* volatiles" as a synonym) will include "juvenile volatiles" and "resurgent volatiles." Either of the respective subdivisions may include volatile agents of "volcanic" origin or those of "plutonic" origin.

Epigene and Meteoric.—Frequent synonyms for "meteoric water" are "atmospheric water," "rain-water," "waters of infiltration," and "water of superficial origin." Few authors have considered the point whether sea-water, seeping into the earth's crust (as it obviously does at some points[1]), is properly included under "meteoric." In one passage Gautier (1910, p. 436) seems to answer this question in the negative; elsewhere (p. 438) he logically includes ocean-water seepages in meteoric waters, since he uses "eaux d'infiltration" as a synonym for "eaux météoriques." Lane (1908*a*, p. 503) puts both fresh and marine waters in the connate division of meteoric waters. Like every lake and river, the ocean is a part of the great circulatory system affecting atmospheric water and certainly very little of the actual sea-water has failed to make at least one complete journey in the cycle of the rains. Further, it may be recalled that the Greek root of "meteoric" means "things lifted up, on high, in air," and that much of the oceanic solution has been

[1] Sea-mills of Cephalonia, Hawaii (proved at borings), etc.

"raised" from the earth's interior by volcanic processes. From the standpoint of etymology, therefore, the geologist has the right to call ocean water meteoric and so recognize the close genetic kinship with the water of atmosphere, river, and lake.

Nevertheless, the tradition that proximate origins should be emphasized and the fact that "meteoric water" and "atmospheric water" are commonly employed as synonyms make it seem wiser to use some expression other than "meteoric" for underground waters of surface origin in general. Such a word is *epigene,* the correlative of Lyell's "hypogene." Geikie (1882, p. 316; 1903, p. 430) employed "epigene" in the sense of "produced on the surface of the earth" (see the New English Dictionary) and made it cover the activities of both fresh and marine water. Geikie's "epigene" is thus broader in scope than the same word used merely in describing underground volatile agents, but contexts should prevent any uncertainty of meaning on that account.

A possible objection to this technical adaptation is that "epigene" is liable to be confused with the "epigenetic" employed in classifying ore deposits. In reply one may urge that "epigene" is an older word than the "epigenetic" of classifications of ore deposits, and is the invaded, not the invader.[2] Only a little care is needed, while reading, writing, or translating, to prevent the imagined confusion.

"*Epigeal*" (lit. "on the earth"; accent on the penultimate syllable) might also be used to include atmospheric, fluviatile, lacustrine and marine waters.

[2] Gürich (*Zeit. für prakt. Geol.,* 1899, p. 175) states that Stelzner, in a then unpublished course of lectures, first applied "epigenetic" to ore deposits. Bergeat (*Centralblatt für Mineralogie,* etc., 1901, p. 84) notes 1894 as the year of its appearance.

It is worthy of mention that "epigenetic" has long been used: in mineralogy as a synonym for "pseudomorphic"; in physical geology (Richthofen and others) as a name for valleys eroded by superimposed rivers; and in biology as a name for a theory of germ evolution. Stelzner thus adapted an already overloaded word. A permissible equivalent might be "apogenetic." According to strict etymology, "hysterogenetic" would perhaps be a still better word for the idea he wished to express, but this term had been pre-empted by Zirkel to describe the later-formed schliers in igneous rocks.

Epigene waters become underground waters either by sinking through the rocks (seepage water) or by being buried with sediments or extrusive lavas or pyroclastics (connate water).

Vadose.—Posepny (1894, reprint, pp. 17, 24) invented the word "vadose" to signify "that part of the subterranean circulation bounded [below] by the water-level [water-table]." He contrasted it with the "deep underground circulation," below the water-table. In this sense Kemp (1906, p. 224; 1907, p. 2; 1914, reprint, p. 2) and W. H. Emmons (1913, p. 28, and 1917, p. 48) use the term.[3]

Suess (1902, p. 134; 1909, p. 630) consciously extended the meaning so that "vadose" should include all seepage water, above and below the water-table, and, as well, all oceans, rivers, clouds, rain, and snow. He even regarded as vadose the hydrogen sulphide bacterially generated in the Black Sea. Delkeskamp (1906, p. 33), Lindgren (1913, p. 82), Beyschlag, Vogt, and Krusch (1914, p. 135) and Lincoln (1911, p. 257) also appear to employ "vadose" as including all seepage water. Omitting any reference to the water-table, Spurr (1905, p. 256) describes vadose water as "surface-derived descending water"; Ries (1916, p. 441), as "descending surface water"; Doelter (1906, p. 14) and Clarke (1916, p. 213), as "superficial" water or "waters of infiltration."

Lane (1908*a*, p. 505) and von Wolff (1914, p. 118) make "vadose" a synonym of "phreatic." Keilhack (1912, p. 73) makes "vadose" cover all waters other than magmatic (his "juvenile").

The present writer (1914, p. 249) has used "vadose waters" as equivalent to "seepage waters" or "waters of infiltration," but now believes it better to adhere to Posepny's original definition, which in general gives a clear mental picture. In an arid region where there may be no distinct water-table,[4] all the seepage water is to be classed as vadose.

Phreatic.—Daubrée (1887, p. 19) invented "phreatic" from

[3] In a foot-note (1917, p. 46) Emmons erroneously states that "Posepny includes in the 'vadose' circulation water below the 'permanent water level.'"

[4] According to a verbal communication from Professor W. Lindgren.

a Greek expression for "well." Referring to what is popularly called ground-waters, he wrote (in free translation): "It will be convenient if they bear a cosmopolitan title, like *phreatic,* which expresses the fact that they supply *ordinary* wells and which is a term that would be understood by the Greeks." Originally, then, the word meant seepage water and particularly that below the water-table. It was so used by Hay (1892, p. 8) and McGee (1894, pp. 16, 42). The new English Dictionary (1909) defines it "of or pertaining to a well."

Suess (1909, p. 655) appears to have included in "phreatic water" that of connate origin as well as seepage water. Lane (1908*a*, p. 505) makes "phreatic" a synonym of "ordinary spring" or "vadose" water. Von Wolff (1914, p. 118) regards "vadose or phreatic" as including connate waters, in spite of their very definite distinction by Lane, the author who first suggested "connate" as a technical term in geology.

The writer believes that the history of the word and practical expediency should make "phreatic" mean the infiltered waters which are bounded above by the water-table.

Phreatic waters are typically migratory, being driven by gravity and vapor pressure. The heat for changing density or vapor pressure may be derived from the earth's general supply, or developed in dynamic metamorphism, or derived from intrusive magma. Locally, however, seeping water may be arrested in its movement and, as free water, occluded water, water in solid solution, or water in chemical combination, remain stationary for an indefinite time.

Seepage.—Thus, all *seepage* waters or waters of infiltration, fresh or marine, are divisible into two physical parts, separated by the water-table: vadose above and phreatic below.

Connate.—In 1908 Lane (1908*b*, reprint, p. 1) wrote: "Such waters laid down with the strata when they were laid down may be called connate waters, for short"; and (1908*a*, p. 502) again described them as "buried with the beds in the first place." Though he stated magmatic water to be "in a sense connate in the magma," Lane's various papers appear to show that he in-

tended his new term not to apply to water and other volatile substances trapped in igneous rock at the time of its crystallization from magma. He gave "syngenetic" as an alternative expression for "connate." Connate water may be marine or fresh.

A considerable number of geologists, including Clarke, Lawson, Leith and Mead, Lindgren, von Wolff, and the writer, have found "connate" very useful in published descriptions and discussions. In the sequel the word will be used according to the Lane definition, with the additional notes: That epigene water buried in the cavities of surface lavas or in tuffs or other pyroclastics are also, like the epigene water buried in ordinary sediments, regarded as connate; and, secondly, that volatile substances typified by the carbon dioxide of limestone or the sulphur trioxide of gypsum are also connate in a technical sense. Typically, connate water or gas is stagnant. At first it may be free or combined. If initally in the free state, it may, through diagenesis or metamorphism, become occluded, go into solid solution, or become chemically combined. However, enormous volumes of connate water have obviously been expelled and set moving through the rocks either by diagenetic settling of sediments or pyroclastics, or because of the new crystallizations involved in static or dynamic metamorphism, or because of mere orogenic pressure, or because of the generation of heat with consequent increase of vapor tension. The heat concerned may be from the earth's general supply, from a zone of dynamic metamorphism, or from intrusive magma.

OLDER CLASSIFICATIONS.

Systematic discussion of the origin of underground "volatiles" has been largely confined to the writings of workers in the problems of ore deposits, and these authors have specialized on the waters, seldom considering those volatile solutions chiefly composed of material other than water. Among the authors who have recently given attention to the matter are: Posepny; Kemp; Lane; Ransome; Gautier; Beyschlag, Vogt, and Krusch; Lindgren; Lawson; and von Wolff.

Posepny recognized only two classes of waters, corresponding to his "vadose underground circulation" and "deep underground circulation."

Kemp (1902, reprint, p. 2) notes two classes: those derived "from eruptive rocks" and those derived "from meteoric sources, possibly during sedimentation." He finds the heat essential to promote circulation in: (1) dynamic crushing or chemical reactions; (2) the normal increase of temperature with depth; and (3) igneous intrusions.

Lane (1908*a*, p. 503) offers the following scheme:

I. Meteoric group.
   (*a*) Rain, vadose, or *pluvial* waters.
   (*b*) Buried or *connate* waters.
II. Juvenile or volcanic.
   (*a*) Magmatic.

Lindgren (1913, p. 82) classifies underground waters as: (1) vadose, (2) magmatic, (3) connate, and (4) "water originally of surface origin and contained in the pores of the rock, or in chemical combination, has by subsidence of the crust been carried to deeper and warmer levels and ascends from these by a sort of distillation."

The present writer (1911, p. 57) has reviewed "in tabular form, the whole group of gases and vapors which are engaged in volcanic and subvolcanic activities," publishing this table:

Magmatic fluids (volcanic; internal)	Juvenile	Emanations directly from abyssal injection.
		Emanations from primary solid abyssal country-rock.
	Resurgent	Vadose and connate fluids absorbed in the syntectic process.
		Vadose fluids absorbed independently of rock assimilation.
Phreatic fluids (subvolcanic; external)		Vadose.
		Connate.

In the table "vadose" is used in the broader meaning of seepage waters; therein the writer followed Suess and certain

authors on ore deposits. In the classification now to be proposed the word is employed with Posepny's definition.

Von Wolff (1914, p. 118) recognized among the volatile substances important in volcanology:

I. Vadose oder phreatische Bestandteile.
II. Magmatische Bestandteile.
  (*a*) Juvenil magmatische, d. h. primäre.
  (*b*) Resurgent, d. h. vadose oder konnate Fluida.

He adds the note (translated): "Of the vadose substances Lane called those 'connate' which are enclosed in sediments at the time of the formation of the latter." Evidently von Wolff's use of "vadose" and "phreatic" does not in either case correspond to the original definition.

PROPOSED CLASSIFICATION.

The following table represents the writer's attempt at a systematic grouping of underground "volatiles" on the basis of proximate origins. Classification on the basis of ultimate origin would have no practical value, since most, if not all, of the earth's surface water and gases were once probably juvenile.

UNDERGROUND VOLATILE AGENTS.

A. MAGMATIC or HYPOGENE (includes volcanic and plutonic).
  I. JUVENILE (primitive, virgin, original-magmatic).
    a. In liquid magma.
    b. In crystallized igneous rocks and minerals, as occlusions, solid solutions, and chemical compounds.
    c. *Expelled,* from magma or igneous rock by crystallization or heat; may remain free or go into solid solution or new chemical compounds.
  II. RESURGENT (secondary-magmatic).
    a. In liquid magma.
    b. In crystallized igneous rocks and minerals, as

occlusions, solid solutions, and chemical compounds.

c. Expelled, from magma or igneous rock by crystallization or heat; may remain free or go into solid solution or new chemical compounds.

B. EPIGENE or EPIGEAL (includes underground atmospheric and marine water and associated gases).

I. SEEPAGE (fresh or marine waters of infiltration).

1. *Vadose* (above the water-table).

2. *Phreatic* (below the water-table).

a. Arrested (free, occluded, in solid solution, or in chemical combination).

b. Migrating, because of gravity, the earth's general heat, the heat of orogenic crushing, or the heat of igneous intrusion.

II. CONNATE (fresh or marine waters buried with sediments or surface volcanics).

a. Stagnant (free, occluded, in solid solution, or in chemical combination).

b. Expelled, by diagenetic settling, crystallization during metamorphism, orogenic stress, the earth's general heat, the heat of orogenic crushing or metamorphic changes, or the heat of igneous intrusion.

C. MIXED TYPES.

The primary divisions (magmatic, epigene and mixed) and the secondary divisions (juvenile, resurgent, seepage and connate) are directly founded on origin. The finer divisions are descriptive of the actual locations and states of the "volatiles." Moving "volatiles" are specially significant in geology and the causes of their movement are briefly indicated. Both classes of seepage waters are typically in movement, but a juvenile, resurgent, or connate fluid will not migrate from the place of its proximate origin unless driven by some particular, powerful force or forces. This quality of emanation is symbolized by the

word "expelled." Thus, expelled juvenile, expelled resurgent, and expelled connate "volatiles" are all to be recognized.

Subjects for debate in connection with this table may be: (*a*) the emphasis on resurgent "volatiles"; (*b*) the inclusion of sea-water in the meteoric class or its exclusion; (*c*) the definition of phreatic water as seepage water below the water-table, with corresponding definition of "vadose"; and (*d*) the use of "epigene" as proposed.

Most of the terms already have international currency—a desirable feature if a classification is to follow an elementary rule in scientific procedure. Men of six different nations have introduced these terms. The objective quality of the concepts underlying the leading words of the table is suggested by the fact that, without any violent changes in the original definitions, the terms make up a comprehensive mental scheme of underground volatile agents.

In offering the classification the writer's purpose is to show that the vocabulary of underground "volatiles" has been developed by the geological profession to the point where unequivocal statement and therefore clear thinking are possible. Both advantages are gravely endangered by such careless usages, definitions, and synonymies as are illustrated in the foregoing historical sketch. Misled by high authority the writer has, for example, employed "vadose" in too broad a sense. Still higher authority is Posepny's original definition coupled with the necessity of fitting together the established words "vadose," "epigene," "seepage," and "phreatic" in a logical scheme. Closer study of the subject has thus led to a conviction of sin and the suggested new classification is in part a confession of it. The need of a common language in science is absolute. No less certain is the advisability of constant revision of the verbal stock-in-trade of science. It is an ungrateful task, but the reviewer may be well repaid if criticism of his product is constructive.

PROPOSED CLASSIFICATION IN PRACTICE.

Of course the scheme outlined is in no sense a classification of the *criteria* for the different kinds of underground "volatiles." That is a quite distinct problem, superlatively important and very difficult. It can be wisely attacked only if its investigator goes into the field already provided with a logical picture of all the known kinds of underground fluids. A knowledge of their relative amounts in the earth's crust is not his first care. He may prefer or believe that resurgent fluids or free-connate water do not exist at all, but just because of his preference or belief he should keep his eyes specially sharp for field evidences that just these kinds of volatile agents do exist. In other words, a classification, as complete as the *experience* of the geological profession can make it, is an indispensable friend and mentor for the best type of field worker. He is ready to mend his classification as experience compels its improvement; he will never go without some kind of a classification. He needs it as an aid to intellectual integrity, to clear sight, to *complete* observation in the field. He will not make a fetish of it, but use it as a tool of high scientific value.

In view of the present lack of criteria for identifying each kind of underground volatile agents, there is little ground for wonder that so few students of springs, volcanoes, or ore deposits have ventured to classify actual, concrete solutions with a great degree of refinement. As a matter of fact, a given example is likely to be of mixed origin. Juvenile gases are liable to be mixed with small or large amounts of resurgent gases or vapors. Pure resurgent emanations are practically impossible. Any gaseous emanation from an igneous intrusive can hardly fail to mix with epigene water. Seepage water may dissolve a small percentage of connate water. Probably in most cases the utmost the investigator of a field problem can do is to determine the origin of the dominant ingredient in the underground solutions involved and secure a more qualitative notion regarding the other ingredients.

Hence, a number of descriptive terms other than those of a complete genetic classification are required for the field worker.

Such familiar expressions as "ascending waters," "descending waters," "oxidizing solutions," "acid waters," "alkaline waters," etc., may often be more directly useful in a scientific way than any term in the proposed classification.

A specially important illustration is found in the connection between metalliferous ore deposits and igneous intrusions. The field data may suffice to show that a primary concentration of ore was effected by magmatic emanations, without declaring what proportion was juvenile and what resurgent. On the other hand, the field data may be so incomplete that the observer cannot decide whether the ore-depositing solution was magmatic "water" or seepage or connate water heated by the igneous mass, though the fact shows the solution to have become capable of depositing ore because it has moved in the hot aureole about the intrusive. In such a case the fluid may be called an "*aureole* solution." Aureole fluids may, then, be juvenile, resurgent, phreatic, or connate, or any mixture of two or more of these kinds. As a class they are to be contrasted with phreatic waters which have not been thermally or chemically affected by any igneous intrusion.

Analogous general terms must be employed in the field study of metamorphism, volcanology, and other phases of geology. Indefinite expansion of the working vocabulary is thus possible and advisable; yet no necessary disturbance of the genetic classification of underground "volatiles" is thereby occasioned. Each of the two sets of terms, the universal and the special, has its own place in the equipment of every thorough investigator of the subject. The proposed classification is, of course, not universally acceptable, but its future editions, showing the confirmation or improvement dictated by the experience of geologists, may possibly serve as a general guide to research.

SUMMARY.

A review of geological literature since 1894, the date of Posepny's notable paper on ore deposits, shows the necessity of stock-taking in the matter of words to be used in describing and

thinking about underground volatile agents. The scope of "juvenile" has been variously defined. The synonymy of "magmatic emanation" has correspondingly varied. The idea underlying the term "resurgent" needs new emphasis; certainly the reason for the concentration of many ores by "aureole" solutions should be considered in terms of the high probability that the chemical nature of those solutions is a function of the resurgent material contained. The technical meanings of "meteoric" and "epigene" should be fixed in terms of a systematic scheme. The definitions and synonymies of "vadose" and "connate" have varied fundamentally. The value of "phreatic" in geology partly depends on a proper definition of "vadose."

Lack of uniformity in definition has interfered with general adhesion to any one of the older classifications of underground "volatiles." The writer has found that, if the original definitions of the established terms connected with this subject be accepted nearly or quite without change, a logical and formally complete scheme can be formulated. The resulting classification, constructively criticized, may have value as an automatic control in the making of field observations and as the embodiment of a universal language in dealing with underground solutions. Alongside it a much more elastic, working or field vocabulary should be developed. After the ability to speak and write about underground solutions with unequivocal meaning has been attained by geologists, they are more likely to attack with success the field criteria for recognizing the different kinds of volatile agents—a truly momentous and pressing problem.

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OIL-SHALE IN THE UNITED STATES.[1]

DEAN E. WINCHESTER.

PAGE.

Introduction 505
Definition and Description 505
Geologic Age 507
Oil-shale of the Eocene Green River Formation 508
Distribution 508
Origin of Shale-oil 510
Value 512
Distillation 517

INTRODUCTION.

Definition and Description.—Before entering upon a discussion of this subject it is essential that there be a clear understanding as to what is meant by the term oil-shale and how an oil-shale differs from an oil sand. It is from the oil sand that the world's supply of petroleum is largely drawn to-day, and it may be in place to suggest that it is the oil-shale which may supply a great proportion of the oil of the future. Petroleum may be obtained from an oil sand by penetrating it, but shale-oil must be obtained by destructive distillation of the shale after it has been mined like coal. The definition of oil-shale furnished by E. H. Cunningham-Craig[2] in his recent article on "The Origin of Oil-shale" may well be used, although a great many students of the subject will differ with that author in his conclusions as to the origin of the oil. "Oil-shale is an argillaceous or shaly deposit from which petroleum may be obtained by distillation but not by trituration or treatment with solvents."

In the United States oil-shale from various geologic formations ranging in age from Devonian to Eocene has been examined

[1] Published by permission of the Director of the U. S. Geol. Survey.

[2] Cunningham-Craig, E. H., "The Origin of Oil-shale," *Royal Soc. of Edinburgh, Proc.*, vol. 36, pp. 44-86, 1916.

by the writer, although most of the study has been concentrated on shale of the Green River formation (Eocene), which is the richest of the shales seen. However, the same general characteristics are evident in all oil-shale. Good oil-shale is black or brownish black in color except on weathered surface, where it is bluish white or white. The shale is fine-grained, usually slightly calcareous and in most cases free from grit. It is tough and in thin-

FIG. 18. Characteristic weathering of oil-yielding paper shale. Northwestern Colorado.

FIG. 19. Characteristic weathering of rich, massive oil-shale. T. 1N. R 100 W. Colorado.

bedded specimens remarkably flexible (see Fig. 18), the latter quality distinguishing it from ordinary carbonaceous shale, which is brittle. All oil-shale is made up of thin laminæ, although in some specimens (see Fig. 19) this is not apparent until after the rock has been heated and the oil driven off. When freshly broken, oil-shale gives off a peculiar odor like petroleum, although the rock actually contains but little oil which may be extracted by solvents. Thin splinters of oil-shale will burn with a very sooty

flame and give off an asphaltic odor when ignited with a match. Oil-shale is heavier than coal, the shale of the Green River formation having an average specific gravity of 1.6.[3] The richer shales are lighter in weight than the leaner ones. Oil-shale of this formation has an average of about 60 per cent. of ash[4] as compared with an average of less than 10 per cent. for good coal.

Geologic Age.—As mentioned above, the shales of the Green River (Eocene) formation of Colorado, Utah, Wyoming and Nevada are the richest extensive deposits so far examined and compare very favorably with the oil-shales which have been worked for more than half a century in Scotland and France. Beds of shale of this age are known over wide areas in northwestern Colorado, northeastern Utah, and southwestern Wyoming, and there are small areas of rich shale in eastern Nevada.

Shales of Cretaceous formations of the Rocky Mountain States have not so far been found valuable as a source of petroleum by distillation, although samples from a number of places have been examined.

Black shales associated with coal beds of Triassic age in North Carolina will yield oil on distillation, but as yet only a single sample has been tested, and little is known concerning the extent of the rich beds or their location.

The diatomaceous Tertiary shales in the California oil fields are often unpregnated with oil and may eventually become the source of commercial quantities of oil and by-products.

Shales of Carboniferous age from a number of localities have been examined, and the results are very encouraging. Samples of so-called "roof slate" from coal mines in Kentucky and Illinois have in some cases been found capable of yielding as much as 16 gallons of oil per ton shale, and cannel-like shale in western Pennsylvania has been found to be considerably richer (45 gal-

[3] Woodruff, E. G., and Day, D. T., "Oil-shale of Northwestern Colorado and Northeastern Utah," U. S. Geol. Survey Bull. 581, p. 3, 1914.

[4] Winchester, D. E., "Oil-shale in Northwestern Colorado and Adjacent Area," U. S. Geol. Survey Bull. 641, p. 161, 1916.

lons in one case).[5] Oil-shale of probable Carboniferous age yielding 24 gallons of oil per ton shale is present in southwestern Montana. It is to be hoped that the future may provide more careful study of these shales as there appears to be an opportunity for rich returns.

The Devonian black shales of the middle and eastern States were the first to attract attention, in fact, before the discovery of petroleum in the United States, according to Baskerville,[6] there were a large number of companies organized and several plants erected to get oil by the distillation of shale and like substances. Recently G. H. Ashley, of the United States Geological Survey, has made brief study of the black shales of the eastern States, and the results are published as a bulletin[7] of the United States Geological Survey. Devonian shales have been found to yield not more than 20 gallons of oil per ton shale, but there is need for more detailed study in this field.

OIL-SHALE OF THE EOCENE GREEN RIVER FORMATION.

Distribution.—Inasmuch as the oil-shales of the Green River formation are liable to be the first developed in this country because of their richness, a brief outline of their location and extent as well as character and condition will be added. Approximately 5,500 square miles in northwestern Colorado and northeastern Utah are underlain by beds of oil-shale thick enough to mine and apparently rich enough to warrant the development of an industry for the manufacture of shale-oil and other products. It is estimated that this shale is capable of producing ultimately several times as much crude oil as has been produced from wells in the United States to date. Although the beds vary in thickness and number at different places along the outcrop of the Green River

[5] Ashley, G. H., "Oil Resources of Black Shales of the Eastern United States," U. S. Geol. Survey Bull. 641, p. 319, 1916.

[6] Baskerville, Charles, "Economic Possibilities of American Oil-shales," *Eng. and Min. Jour.*, vol. 88, pp. 149–154, 195–199, 1909.

[7] Ashley, G. H., "Oil Resources of Black Shales of the Eastern United States," U. S. Geol. Survey Bull. 641, pp. 311–324, 1916.

formation, there are but few places at their outcrop along the southern edge of the Uinta Basin in Colorado and Utah where there is not a thickness of more than 10 feet of shale that will yield more oil per ton than the average which is being obtained from shale in the oil-shale industry of Scotland, and at many places there is an aggregate thickness of more than 100 feet of rich oil-shale. At least one bed of oil-shale 6 feet or more thick yielding at least 40 gallons of oil per ton shale is present at most places. In the Uinta Basin the shale beds are nearly horizontal and in considerable areas near enough to the surface to make mining by stripping methods possible.

The oil-shales of the Green River formation are distributed through a stratigraphic interval of perhaps 1,000 feet of beds although at most places beds sufficiently rich to be of economic interest are confined to a zone of less than 200 feet thickness. The individual beds vary in thickness and character from place to place, but the apparent persistence of individual members of the formation is remarkable. For instance, in eastern Utah and western Colorado along the southern rim of the Uinta Basin three thin beds of sandstone within the rich oil-shale zone, each peculiar lithologically, have been observed interbedded with the rich shale over a large area. Again, between Desolation Canyon of Green River (see Pl. XXIX., *a*) and the east line of Utah, an air-line distance of about 50 miles, a very peculiar concretionary-like bed occurs less than 50 feet below the shale. Careful study of a single bed of oil-shale has not been made except in southern Wyoming, where there is but a single bed of rich shale in the section, and this is separated into alternating thin benches of rich and lean shale (see Pl. XXIX., *b*), with an aggregate thickness of about 3 feet. This bed outcrops for a distance of 18 or 20 miles along the west side of Green River south of the Union Pacific Railroad and appears from the few tests made to provide a fairly uniform richness of the aggregate thickness, although the number and physical character of the benches vary greatly from place to place.

Although including vast areas of rocks belonging to the Green River formation, the Green River Basin in southwestern Wyoming does not contain beds of rich shale except at a few places, and there the beds are thin.

Origin of Shale-oil.—The Green River formation or that part of it including the oil-shales consists of remarkably persistent and thinly bedded shales with some sandstone and at places oölite and limestone. The beds were laid down in fresh water which had an enormous expanse and was deep enough so that wave action had little effect on the sediments. The shale is in most places free from grit and contains an immense amount of vegetable matter; the richer beds show by far the greater amount of such material. Singularly enough such low plant forms as the blue-green algæ are represented in great abundance and in state of almost perfect preservation. Pollen grains are present which came from conifer trees which grew on land perhaps at considerable distances from the great inland lake in which the shale was deposited. There is also a vast amount of organic material which is too macerated for identification. Complete insects and excellently preserved diptera larvæ as well as fish scales and even perfect fish skeletons have been found, but in most hand specimens of the shale there is little evidence of other than plant life.

At the time of his death Dr. C. A. Davis was engaged in a microscopic study of the oil-shales and had examined a large number of thin sections. The following list of the plants identified shows the range of plant life preserved in the shales.

FLORA OF THE OIL-SHALE OF THE GREEN RIVER FORMATION.

[Notes by C. A. Davis (March 30, 1915). (See Pl. XXX.)]

(*a*) Bacteria, *Crenothrix* and similar low filamentous types.
(*b*) Myxophyceæ: Blue-green Algæ.
(*c*) Algæ (1) Protococcaceæ: *Protococcus Pediastrum.*
(2) Conjugatæ: *Spirogyra.*
(*d*) Fungi: Saprophytic moulds, etc.
(*e*) Mosses: Spores probably from these plants.
(*f*) Pteridophyta. Ferns. Annuli from fern sporangia.

(*g*) Spermatophyta.

(1) Gymnospermæ: Pinaceæ. Pollen of Picea and Pinus.

(2) Angiospermæ. Pollen and fragments of cells, tissues, etc. Bark cells and residues, small pieces, poorly preserved. In addition there are abundant and well preserved remains which are of good size and of frequent occurrence, which seem to be structureless so far as cellular structures are concerned. However, they have definite and pretty regular forms and, in *Dictyonophora*, definite areas which carry well-marked and characteristic patterns which seem like cells, but which show no cell walls. These anomalous forms seem to have been the most abundant organisms in the waters in which the shales were laid down and are evidently vegetables of a low order of development. They are manifestly in place as they grew, since they do not show in pressed down masses, but were buried in natural positions, very slowly.

It is significant that shale showing little vegetal content is found to yield but little oil while rich shale always contains much vegetal debris, and the quantity of fish remains evidently appears to have no relation to the yield of oil or ammonia. This, together with the fact that much more oil may be obtained from the shale by destructive distillation than by the action of solvents, would seem to disprove Cunningham-Craig's[8] idea that the oil in American oil-shale is there as oil, having migrated there from other parts of the earth and been adsorbed by the minute particles of shale, and dried so that it is not extractable with solvents, and goes to prove that at least in the Green River shales of the United States the oil is indigenous to the shale, being formed from the vegetal remains in the shale partly by the slow process of nature, partly by the violent destructive distillation in the laboratory. In regard to this Mr. Davis made the following notes:

RELATION OF BITUMINOUS COMPOUNDS TO MINERAL MATTER IN THE GREEN RIVER OIL-SHALE.

(Notes by C. A. Davis dated October 30, 1914.)

From the optical standpoint, the shale is composed of (*a*) organic matter, (*b*) bituminous matter, and (*c*) mineral matter.

[8] Cunningham-Craig, E. H., *loc. cit.*, p. 79.

The amount of bituminous matter increases as the mineral matter decreases, *i. e.*, it increases with the increase of organic matter in the shales. However, it needs only a casual inspection of the shales in place to see that (*a*) the beds run very irregular in ash content, some high in ash occurring between those very low in mineral matter; (*b*) the rich shales are very compact and almost as impervious as rubber, being made up of what seems to have been partly decomposed remains of minute plants, algæ, fungi, spores, pollens, bacteria, etc., embedded as a jelly-like mass; (*c*) between these there are few, if any, interspaces, and such grains of mineral matter as are present seem to be firmly embedded in this jelly-like mass. Some thin sections show the silt to be exceedingly fine and in laminæ which are much thinner than the laminæ of combustible material of the section. In fact, the mineral part of the rich bed is physically so minute that if it were the sole original material into which the bituminous matter was injected, the intrusion must have greatly distorted the beds overlying the invaded ones, but even where the layers are very thin no such distortion is observable; (*d*) if the invasion by the bituminous matter occurred while the beds were still forming, and the grains were free to move, it would be necessary to assume that the silts were dry, a possibility that seems barred by the great number of algæ and other water plants present in the deposit. (*e*) If the silt and sandy layers were dry it is also difficult to see how the finer, more compact layers absorbed and retained so much more bituminous matter than those containing larger grains and having a large number of capillary interspaces, for although a given volume of clay will hold more water than the same volume of sand, it is evident in these oil-shales that the rich beds, volume for volume, contain a vastly smaller amount of mineral matter than the leaner sandy beds do. (*f*) If, on the other hand, the bituminous matter originated in the highly organic beds and began to migrate under pressure or other factors, the most obvious place for it to be stored first would be in the adjacent more sandy beds, and from this theory it would be expected that the more sandy beds would yield larger percentages of more volatile petroleum than the others. (*g*) If, however, the bituminous matter is held in the partly bitumified organic matter seen in an incompletely decomposed state in the shale, heat might decompose the parent fossil material, and petroleum in quantities proportionate to the percentages of the plant remains might be produced, and from both kinds of shale the product would be essentially the same. These facts seem to be developed in reported tests.

Value.—It is unfortunate that the present stage of development of oil-shale in the United States makes it necessary to base

all statements and estimates on the study of shale at the outcrop. We have no mines from which to obtain samples to study the effect of weathering, variation of shale with depth, or the many other subjects which have their bearing on the future possibilities of the shale. It seems fair to assume that weathering does not affect the Green River oil-shale to distances of more than a few feet back from the outcrop, because most oil-shale is altered in physical appearance to a distance of inches rather than feet from an exposed surface. At one place a bed about 7 feet thick sampled after chipping away the obviously weathered material gave a yield of 32 gallons of oil per ton, whereas a foot and a half back of this outcrop (sample obtained after blasting away the exposed shale) the same bed gave 55 gallons per ton shale. That shale, under cover, may be expected to be richer than that represented in many samples examined so far is indicated by the results of this test. The samples upon which this report is based were taken in the same way as the first sample, and it may, therefore, be possible to increase the figures for the yield of outcrop samples by several per cent. without exceeding the yield which may be expected from unweathered material.

In the process of distillation of oil-shale three principal and valuable products will be made—(1) shale-oil, (2) ammonia, (3) uncondensed gas—the quality and quantity of each depending on the conditions of heating. Temperature and pressure will have important bearing on the quality and quantity of oil and permanent gas, while the presence or absence of steam in the heated retort will affect the yield of ammonia.

The shale-oils examined by the United States Geological Survey have been those obtained by the destructive distillation of oil-shale in small laboratory and field retorts and may or may not represent the oil which will eventually be derived in commercial practice. The oil gotten by the distillation is a cracked oil and obviously different from that contained in the rock if such is present, and it is quite probable that retorts used in future commercial practice will be built to produce the greatest quantity of a given desired product. Fractional distillation of the shale-oil obtained in the small testing apparatus used in the field gave an

EXPLANATION TO PLATE XXIX.

A. Desolation Canyon of Green River, Utah.

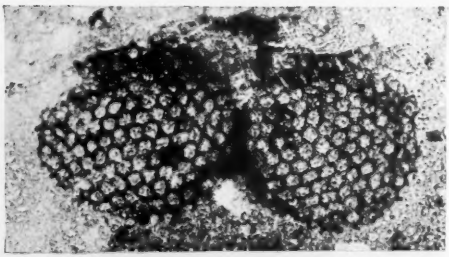
B. Bed of oil-shale south of Green River City, Wyo. Shows characteristic weathering of bed containing alternating rich and lean benches. Rich benches are more resistant.

A

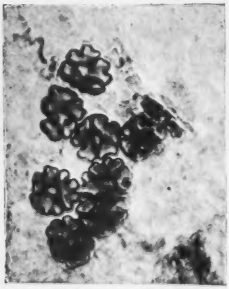
B

Pollen. × 245.

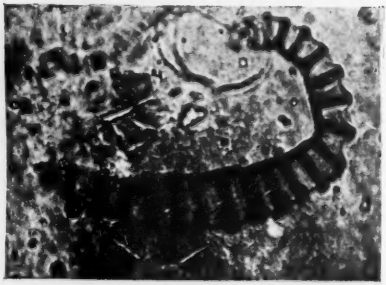
Many-celled spores. × 200.



× 120.



Pediastrum (yellow-green algæ). × 740.



Fern annulus. × 685.

EXPLANATION TO PLATE XXX.

Fossil plant remains. (Common in oil-shale of Green River formation.) From thin sections prepared by C. E. Davis.

average of about 15 per cent. gasoline (distillate up to 175° C.), with 33 per cent. kerosene (175°–300° C.), with paraffin as high as 9.21 per cent. and asphalt average 2 per cent.; sulphur, 0.61 per cent.; nitrogen, 1.7 per cent. Most of the oil was fluid at ordinary temperature, but that from some samples was vaseline-like, similar to the shale-oil of Scotland. The viscosity of the oil seems to bear little relation to its specific gravity, indicating that different samples of shale-oil, obtained in the crude apparatus used to test samples, contained mixtures of hydrocarbons which when put together gave resulting viscosities according to the mixture.

Inasmuch as the oil-shale industry is best developed in Scotland, it is natural to compare our raw material with that of Scotland and to study the processes and results there obtained in order to get an idea of the possibilities of oil-shale in the United States. It is reported that even before the beginning of the present war 20,000 individuals, of which number more than 4,000 were miners, were dependent on the shale-oil industry of Scotland. Geologically the oil-shale of the calciferous sandstone series (Mississippian) of Scotland compares in age more nearly with the black shales of the eastern United States than with the richer shales of Eocene age of the Rocky Mountain region. Structurally the shale beds in Scotland are folded and faulted to a remarkable degree, so that at only a few places are beds present which do not dip at considerable angles, and many of the mines are working beds dipping 30° to 60°, and all mining is underground. As compared to these adverse conditions, dips as steep as 10° are exceptional in the Green River shales, and there are large areas where overburden is sufficiently thin to allow stripping by steam shovel. (See Pl. XXIXB.) Crude distillation tests indicate that the shale of the Green River formation is capable of yielding much more oil than the shale mined in Scotland, although probably the amount of ammonia derivable will be less for the American shales. To offset the smaller costs of mining due to favorable geological conditions American labor costs will be considerably greater than those of Scotland.

From such published information as is available there appears to have been little progress or change in the last twenty or more years in methods or machinery of the Scotch shale-oil industry, and it is quite possible that a careful study of American oil-shale by the chemist and chemical engineer will make possible the production of materials of especial value by methods quite different from those used in the foreign industry. Chemical research may find it possible and practical to reclaim the nitrogen of the shale in forms available for use in munitions as well as soil enriching agents, or the "pyridine compounds" so abundant in the shale-oil obtained by dry distillation may be separable from the oil and may have great value. It is also quite possible that dyestuffs may be developed from the oil-shale by some particular procedure, and it has been suggested that the shale may be of greatest value as a source of producer gas. Whatever may be the special products we now know that it will be possible to develop the shale for its crude oil (including gasoline) and its ammonia for fertilizer purposes.

Oil-shale must be mined like coal, and because of its toughness shale may be much harder to get out of the ground than coal. Whether or not dangerous gas will be encountered in the operation of shale mines in the United States can only be speculated upon, but it is reported that in Scotland neither dust nor gas are a menace to the mines, so that open lights are used throughout the works. The shale after being brought to the surface is crushed and then is ready for the retorts.

Distillation.—The retorts used at present in Scotland are of the vertical type, arranged (according to the patent used) to allow continuous operation, new shale being charged at the top and spent shale taken off at the botton. As the shale passes downward in the retort the heat is increased gradually until in the lower part of the retort a temperature of about 1,300° F. is reached. The vapors from the shale are carried through great lengths of air-cooled pipes, and the liquid products (oil and ammonia water) condense and are conducted into appropriate chambers. The permanent gas is then used for illuminating or

heating purposes. According to Cadell[9] there is sufficient permanent gas formed in the distillation of the Scottish shale to furnish enough heat to accomplish the retorting of the shale, so that once the retorts are heated it is possible to dispense altogether with the use of coal. Shale-oil is then refined to marketable products, the character and amount of which depend not only on the method of refinement used but much on the treatment of the shale when the shale-oil is being driven off. The ammonia in water and gas is converted into ammonium sulphate by the use of sulphuric acid.

[9] Cadell, H. M., "Scottish Shale Industry," *Petroleum World*, vol. 10, p. 230, 1913.

PRELIMINARY NOTE ON THE OCCURRENCE OF CHALMERSITE, $CuFe_2S_3$, IN THE ORE DEPOSITS OF PRINCE WILLIAM SOUND, ALASKA.[1]

BERTRAND L. JOHNSON.

INTRODUCTION.

Chalmersite, $CuFe_2S_3$, has hitherto been classed among the rarer minerals, as its only known occurrence previous to 1912 was as minute acicular crystals in the Morro Velho gold mine in Brazil.[2] It is now known to occur, however, as a prominent constituent of copper ores at eight widely separated localities on Prince William Sound, Alaska, and at one of these localities—in the workings on the Keystone claim of the Threeman Mining Company on Landlocked Bay—it occurs, in association with chalcopyrite, in commercial quantities, and it has been mined, along with that mineral, for several years as an ore of copper. These Alaskan occurrences are the only known occurrences of massive chalmersite, and they are, moreover, the only known occurrences of this mineral in the world outside of the Brazilian locality.

The Alaskan chalmersite was first observed by the writer in 1912 as a soft, pale-yellow, metallic mineral intergrown with chalcopyrite in certain of the copper ores of the Ellamar district of the Prince William Sound region, Alaska. Qualitative tests showed that this mineral was apparently a copper-iron sulphide with a low copper content.

A preliminary reference to its occurrence in the chalcopyrite-

[1] Published by permission of the Director, U. S. Geological Survey.

[2] Hussak, E., "Ueber Chalmersit, ein neues Sulfid der Kupferglanzgruppe von der Goldmine 'Morro Velho' in Minas Geraes, Brasilien," *Centrallblatt für Min., Geol. u. Pal., Jg.*, 1902, pp. 69–71.

Hussak, E., "Ueber die chemische Zusammensetzung des Chalmersit," *Centrallblatt für Min., Geol. u. Pal., Jg.*, 1906, pp. 332–333.

pyrrhotite ores of the Ellamar district was published in 1913,[3] and a somewhat more detailed description, with a chemical analysis by Dr. R. C. Wells, was given in 1915.[4] In the summur of 1916 this copper-iron sulphide was found as an abundant constituent of the ores of several copper prospects on Knight Island in the western part of Prince William Sound. The physical and the known chemical properties of this mineral agreed closely with those of chalmersite, and in January, 1917, through the courtesy of Professors Charles Palache and L. C. Graton, of Harvard University, comparisons were made of the Alaskan mineral with Brazilian chalmersite crystals. Later, choice material from two of the Prince William Sound localities was furnished to Drs. E. T. Allen and H. E. Merwin, of the Carnegie Geophysical Laboratory at Washington, who were at that time engaged in laboratory studies of the copper-iron sulphides. The unknown copper-iron sulphide was magnetically separated from its associated sulphides by Dr. H. E. Merwin, and several chemical analyses, made by Dr. E. T. Allen, of the separated mineral showed definitely that the unknown copper-iron sulphide was chalmersite, $CuFe_2S_3$. The correspondence of the density and specific gravity determinations, by Drs. Allen and Merwin, of the Alaskan mineral and the Brazilian crystals furnished by Prof. Palache also checked this determination.

The writer has in preparation an extended study of the geology of the chalmersite deposits of Alaska and of the paragenesis of the chalmersite, and Drs. Allen and Merwin, of the Carnegie Geophysical Laboratory, are preparing a more detailed statement of the properties and composition of the mineral for inclusion in a forthcoming record of their studies on the copper-iron sulphides.

PHYSICAL AND CHEMICAL PROPERTIES OF THE PRINCE WILLIAM SOUND CHALMERSITE.

The chalmersite from Prince William Sound is a very pale yellow, opaque, massive mineral with a metallic luster. It has

[3] Capps, S. R., and Johnson, B. L., "Mineral Deposits of the Ellamar District," U. S. Geological Survey Bull. 542, pp. 101, 102, 103, 110, 112, 120, 1913.

[4] Johnson, B. L., "Mineral Resources [of the Ellamar District, Alaska]," U. S. Geological Survey Bull. 605, pp. 69–72, 74, 78, 95–96, 97, 108, 1915.

a conspicuous cleavage, and fresh fractures have a pronounced satiny sheen. Its hardness is about the same as that of chalcopyrite. It is strongly but variably magnetic. The specimens tested were less magnetic than some pyrrhotites and more magnetic than others.[5] The specific gravity of the Alaskan chalmersite (4.04; mineral at 25° C., water at 25° C.), determined by Dr. E. T. Allen, is practically identical with that found by Dr. H. E. Merwin for the density of the Brazilian crystals of chalmersite which were loaned for comparison by Professor Palache.[6] Hussak's determination of the specific gravity of the Brazilian chalmersite was 4.68.[7] Approximate determinations of the melting point of the chalmersite from the Alaskan localities, by Dr. E. T. Allen, place it between 910° and 920° C.

ANALYSES OF ALASKAN CHALMERSITE.

Analyst, Dr. E. T. Allen.

	Home Camp Lode, Mummy Bay, Knight Island, Prince William Sound.		Threeman Mining Co., Landlocked Bay, Prince William Sound.		Theoretical Composition of Chalmersite, $CuFe_2S_3$.
	1.	2.	3.	4.	5.
Copper (Cu)	23.69	23.83	23.52	22.67	23.42
Iron (Fe)	41.25	40.70	41.14	41.92	41.14
Sulphur (S)	35.14	35.09	35.30	35.29	35.44
Total	100.08	99.62	99.96	99.88	100.00

The first quantitative analysis of the Alaskan chalmersite was made by Dr. R. C. Wells, in the chemical laboratory of the U. S. Geological Survey, on material containing a small quantity of other sulphides as impurities.[8] Later, the chalmersite in specimens collected by the writer from two Prince William Sound localities about 60 miles apart was magnetically separated from

[5] Personal communication from Dr. H. E. Merwin.

[6] Personal communication from Dr. H. E. Merwin.

[7] Hussak, E., "Ueber Chalmersit, ein neues Sulfid der Kupferglanzgruppe von der Goldmine 'Morro Velho' in Minas Geraes, Brasilien," *Centrallblatt für Min., Geol. u. Pal., Jg.*, 1902, p. 71.

[8] Johnson, B. L., "Mineral Resources [of the Ellamar District, Alaska]," U. S. Geological Survey Bull. 605, p. 95, 1915.

associated sulphides by Dr. H. E. Merwin, of the Carnegie Geophysical Laboratory, and several quantitative analyses of the magnetically separated chalmersite were made by Dr. E. T. Allen. Four of these analyses are given here, together with the theoretical composition of chalmersite.

The percentages of Cu, Fe and S shown by these analyses agree very closely with those calculated from the theoretical formula of chalmersite, $CuFe_2S_3$, which are given for comparison, and the formula for the Alaskan chalmersite calculated from the four analyses given is also $CuFe_2S_3$.

GEOGRAPHIC DISTRIBUTION OF CHALMERSITE DEPOSITS IN PRINCE WILLIAM SOUND, ALASKA.

Only a comparatively few of the many copper prospects of the Prince William Sound region have as yet been examined to determine the presence or absence of chalmersite in the ores from those prospects. Thus far, the chalmersite is known to occur only in the Ellamar district on the eastern shore of Prince William Sound and on Knight Island in the western portion of the sound. It was first discovered in the Ellamar district in ore from the workings on the Keystone claim of the Threeman Mining Co. on Landlocked Bay. It also occurs in that district in the ore from the old Alaska Commercial Co.'s workings (now the property of the Threeman Mining Co.), and in the ore from the workings of the Landlock Bay Copper Mining Co. Both of these properties are on Landlocked Bay. On Knight Island, chalmersite has been found in ore from copper prospects on Mummy Bay (Home Camp Lode); on Drier Bay (Nellie Group, Copper Coin Group, and the Knight Island Alaska Copper Co.'s claims); and on the Bay of Isles (Pandora Group).

GEOLOGIC OCCURRENCE OF THE PRINCE WILLIAM SOUND CHALMERSITE-BEARING ORES.

The rocks of the Prince William Sound region are mainly sedimentary and consist dominantly of graywacke, argillite, slate, and conglomerate, with very minor amounts of limestone, chert,

and jasper. They contain very few fossils and those found are so poorly preserved and so lacking in diagnostic value that no definite age determinations can be made. On the basis of the collections obtained, however, these rocks can be tentatively assigned to the Mesozoic.

The deformation of these sedimentary rocks was followed by two periods of igneous activity—the first, during which large quantities of basic igneous rocks, now largely altered to greenstones, were injected into the sedimentary rocks and poured out upon their surface, and a much later period in which granite stocks were intruded into the folded sediments in various parts of the sound.

Two periods of mineralization are now recognized in the Prince William Sound region, the intrusion of both the greenstones and the granites having been accompanied by mineralizing activities. The mineral deposits may be grouped into two classes—copper deposits and gold-bearing quartz lodes. The copper deposits are associated with the greenstones and were deposited during the period of the basic igneous activity. The gold-bearing quartz lodes are genetically related to the granite intrusions. The copper deposits are replacements and impregnations of sheared or shattered zones in the greenstones, or in the nearby sedimentary rocks. The gold-quartz lodes are fissure fillings in either sedimentary or igneous rocks. The minerals present in the copper deposits include chalcopyrite, chalmersite, pyrrhotite, sphalerite, galena, pyrite, arsenopyrite, gold, silver, epidote, quartz, calcite, chlorite, and breunerite (?). Traces of nickel occur in some of the ores. The gold-quartz deposits contain gold, silver, arsenopyrite, chalcopyrite, galena, pyrite, pyrrhotite, sphalerite, stibnite, albite, calcite, chlorite, quartz, and sericite. Chalmersite is known to occur only in the copper deposits. Moreover, it has been observed only in those copper deposits occupying shear zones wholly or partly in the greenstones, and only in the Ellamar and Knight Island districts. It is not present, however, in all of the copper deposits fulfilling the above conditions in either of these districts.

The principal present known mineral associations of the chalmersite in the chalmersite-bearing deposits of Prince William Sound are shown in the accompanying table:

TABLE I.

PRINCIPAL PRESENT KNOWN MINERAL ASSOCIATIONS OF CHALMERSITE IN PRINCE WILLIAM SOUND MINES AND PROSPECTS.

Localities.	Minerals.									
	Chalmersite.	Chalcopyrite.	Pyrrhotite.	Sphalerite.	Pyrite.	Galena.	Arsenopyrite.	Epidote.	Quartz.	Calcite.
Ellamar District.										
Landlocked Bay.										
1. Keystone Claim, Threeman Mining Co.	●	●	●	●	●	●			●	●
2. A. C. workings, Threeman Mining Co.	●	●	●	●		●	●	●	●	
3. Landlock Bay, Copper Mining Co....	●	●	●	●					●	●
Knight Island.										
Mummy Bay.										
4. Home Camp Lode.....	●	●	●	●					●	
Drier Bay.										
5. Copper Coin Group.	●	●	●						●	
6. Knight Island, Alaska Copper Co.	●	●	●	●					●	
7. Nellie Group.	●	●	●						●	
Bay of Isles.										
8. Pandora claim.....	●	●	●						●	

Chalcopyrite is invariably present in the chalmersite ores and it is intimately intergrown with the chalmersite. Pyrrhotite is also present in the chalmersite-bearing ores, but does not show the intimate relations with the chalmersite that the chalcopyrite does. In several of the Knight Island deposits, for instance, pyrrhotite is very scarce in those parts of the orebody in which chalmersite is most abundant, but it appears in abundance in association with chalcopyrite in other parts of the same deposit

where little or no chalmersite is present. Quartz is usually present in small amounts in the chalmersite ores which, however, are dominantly sulphides. The ore from the Keystone claim of the Threeman Mining Co. on Landlocked Bay contains, besides the minerals listed above, gold, silver, and traces of nickel. Gold and silver are also reported in some of the Knight Island chalmersite-bearing ores. Tremolite was observed by Drs. Merwin and Allen in a microscopic examination of ore from the Home Camp lode on Knight Island.

THE PEAT DEPOSITS OF MINNESOTA.

E. K. Soper.

INTRODUCTION.

It has been known for some time that Minnesota contains large deposits of peat, but, up to the present, no detailed information has been available regarding the quantity and quality of Minnesota peat, and the uses to which it is best adapted. An investigation was undertaken to determine these facts and some of the results are outlined below. The work was done by the writer for the Minnesota Geological Survey and Mr. Percy G. Cowin assisted in the field.

CONDITIONS OF PEAT FORMATION IN MINNESOTA.

Occurrence.

Peat deposits form only in depressions filled with water, such as lakes and ponds, or on low, flat, or very gently sloping surfaces, where the water table is constantly at the surface, therefore always wet. Plate XXXI. shows various types of Minnesota peat bogs.

Climatic Influences.

The most important climatic influences in peat formation are (1) regular and abundant rainfall, and (2) high humidity of the air. A third should be mentioned, namely, a cold or temperate climate, but this is not absolutely necessary, for peat deposits are known in warm climates such as that of Florida.

The conditions essential to the formation of extensive peat deposits are prevalent in eastern North America north of 40° N.

Latitude and most of the peat in the United States lies north of 40° N. Latitude and east of the Dakotas. The largest and deepest deposits in North America occur within this area, along the Canadian boundary, on both sides of the line.

The influence of climate upon the origin and accumulation of peat is well shown in Minnesota; the largest and deepest peat bogs are all in the northern portion of the state, where the mean annual temperature is 8 to 10 degrees colder than in the southern counties.

The least rainfall is in the northwest corner of the state, where there is no peat whatever. From the North Dakota boundary, the rainfall increases steadily to the eastward as far as the Lake Superior region, a vicinity in which are found some of the largest peat bogs in America. There are some localities in northern Minnesota, chiefly north of Lake Superior, where, in spite of the cold climate and abundant precipitation, there is little or no peat. This is due to the topography of these regions, which is so hilly and rocky that no marshes or bogs could form.

Topographic Influences.

Just as the climate of a region controls in part the quantity of peat which may form, so the topography controls the distribution of the deposits. Given all conditions favorable except topography, no peat would form, since its formation requires the existence of basins, depressions, or flat, undrained areas, in which the plant remains can accumulate and be protected from decay and decomposition.

The principal topographic divisions in Minnesota are: (1) a complex system of morainic belts and partially filled kettle holes; (2) gently undulating belts of modified glacial drift, such as outwash plains, clayey till plains, etc.; (3) several large lake beds, the most important of which are those of ancient Lake Agassiz in the northwestern part of the state, the large lake which once covered a part of St. Louis County, and the delta deposits of the glacial Lake Superior in the northwestern portion of the state. In some localities, especially in northeastern Min-

nesota, rock hills rise above the glacial drift. The largest and most numerous moraines occur in northern and central Minnesota, and many peat bogs, some of which are very deep, occupy the depressions and basins in these morainic belts.

The altitudes of Minnesota range from 602 feet, the level of Lake Superior, to 2,230 feet, the highest point in Cook County in the northeast corner of the state. This gives a maximum relief of 1,628 feet. Most of the state, however, has a gently undulating surface of slight relief, with extensive flat areas which represent ancient glacial outwash plains, or old lake beds, many of which are covered with peat deposits.

Effect of Glacial Influence upon Peat Formation.

Nearly all the peat deposits in the northern United States (Minnesota, Wisconsin and Michigan), as well as those of eastern Canada, owe their origin directly or indirectly to the influence of glaciation. Before extensive deposits of peat may be formed, the three essential factors in peat formation, *i. e.*, climate, topography and vegetation, must all be favorable. In northern Minnesota the topography is the direct result of glaciation, while the climate and vegetation have been indirectly controlled by the same glacial influences.

At least 95 per cent. of the peat in Minnesota lies north of Minneapolis and St. Paul, and hence it is necessary to consider only the glacial drift of the northern part of the state in studying the influence of glacial drift upon peat formation. All the peat in Minnesota rests upon glacial drift, or modified drift. In northern Minnesota there are only two important drift sheets exposed at the surface and in contact with the peat. These are: (1) The *Young Red Drift,* in northeastern Minnesota, and (2) the *Young Gray Drift,*[2] in the northwestern and central parts. Both of these drift formations probably belong to the youngest, or Wisconsin Stage of Pleistocene Glaciation. The largest peat bogs overlie the water-sorted gray drift which constitutes the

[2] Leverett, Frank, "Surface Formations and Agricultural Conditions of Northwest Minnesota," Minn. Geol. Survey Bull. 12, p. 32.

bed of ancient Lake Agassiz, which in turn rests upon calcareous gray drift. A careful study of the peat bogs of northern Minnesota, with reference to the nature of the drift upon which they rest, shows that the peat deposits are not confined to any single drift formation, but that they occur over areas of red as well as of gray drift. The largest deposits, however, exist within the area of gray drift, but this is due to topographic conditions rather than to any influence exerted by the composition of the drift.

Relation of Marl Beds to Peat Formation.

Many lakes in central and northern Minnesota contain valuable deposits of marl, the origin of which is clearly due to precipitation of lime carbonate from solution in the lake waters through the agency of the plant, *Chara*[3] (stonewort). When the *Chara* are displaced by the invasion of other water-loving plants, the accumulation of marl in the lake may be followed by the accumulation of peat. Under such conditions, which were frequently observed in Minnesota, the lake may ultimately become completely filled with marl and peat. The marl always lies on the bottom and is not sharply separated from the overlying peat. The peat may continue to form after the lake is filled by the accumulation of successive layers of dead plant remains on the surface of the bog. The presence, therefore, of a considerable number of peat bogs in Minnesota, underlain by beds of pure marl, is readily explained when the history of these marl deposits is known.

Depth of Peat Accumulation.

The depth of peat accumulation depends chiefly upon the form of surface at the site of accumulation; the climate; amount, and character of vegetation. The form of land surface is the principal factor controlling the depth.[4] Peat deposits formed in

[3] For an excellent account of the origin of marl see Davis, C. A., Michigan Geol. Survey, Vol. 8, 1900–1903.

[4] See Shaler, N. S., "General Account of the Fresh Water Morasses of the United States," U. S. Geol. Survey, 10th Annual Report, p. 262.

lakes or basins are usually deeper than those formed on flat surfaces or in slight depressions. It should be understood, however, that the depth of a given basin does not necessarily determine the thickness of peat which may accumulate there. Under certain conditions, peat may continue to accumulate after the basin has become filled, by the addition of successive layers of dead vegetation to the surface of the bog, thus building up the deposit above the former lake level, or above the original rim of the basin. Numerous examples of such deposits were observed in the northern part of the state.

The peat deposits of Minnesota vary in thickness from a few inches up to 63 feet. The deposits in the southern portion of the state are generally much shallower than those in the north, because there the topography, climate, and vegetation are all unfavorable to thick accumulations. The maximum thickness noted in the southern bogs is 18 feet. The majority of the deposits of that region, however, are less than 5 feet thick. In the north many of the bogs are 20 to 25 feet thick in the center, especially those of the filled-lake type.

The average depth of peat in the great built-up deposits occupying portions of the bed of Lake Agassiz in north-central Minnesota is 7 to 9 feet but increases to 18 or 20 feet in many places. These deeper areas evidently represent depressions and hollows below the general surface of the old lake bed, which probably remained as temporary ponds and lakes after the main body of water had disappeared from this region.

Rate of Peat Formation.

The rate of peat formation varies with the amount of vegetation, moisture and other conditions. Dana[5] gives as a *maximum* rate of peat accumulation 1 foot in five or ten years. This maximum has not been reached in Minnesota, in the writer's opinion, and there is evidence that the rate of growth has been very much slower.

Since all of the lakes of the state are of glacial origin, it is not

[5] Dana, James D., "Manual of Geology," 4th ed., p. 154.

unreasonable to assume that they are approximately of the same age, and that peat accumulation began in many of these lakes at about the same time. At those places where the lakes became filled with peat to the original water level, after which peat accumulation stopped, it is impossible to get any significant evidence as to the rate of accumulation, since there is no means of determining how long a time has elapsed since peat formation stopped. In other lakes, however, peat formation did not stop when the lake became filled to the rim of the basin, but peat continued to form, building up the surface of the bog many feet above the original lake level by the addition of successive layers of vegetation. In deposits of this type, where peat is in active process of formation today, the evidence obtained from the study of numerous sections of the deposits indicates that peat accumulation has been continuous from the time it first began, which probably was not long after the origin of the lake. If this assumption be even approximately correct, we have a rough means of estimating the rate of peat accumulation. Reckoning the time which has elapsed since the close of the Pleistocene Glacial Period at 10,000 to 30,000 years, and taking 18 feet as the average thickness of some of the largest filled-lake bogs, and assuming the accumulation to have been uninterrupted by fires or drought, we get a growth of .022 to .0072 inches per year as the average annual rate of peat accumulation in northern Minnesota, in bogs of the filled-lake type.

In the built-up deposits, formed on flat, wet land surfaces by successive layers of plant remains, the rate of peat accumulation is probably much more rapid than in filled-lake deposits.

Classification of Minnesota Peat Deposits.

The most logical classification of peat deposits is probably that based upon the type of land surface upon which the peat is formed. Upon such a basis the following types of deposit may be recognized:

1. Deposits which represent filled lakes or ponds (Fig. *A*, Pl. XXXII.).

2. Deposits which represent accumulations built up on moist depressions, or flat, undrained areas (Fig. *B*, Pl. XXXII.).
3. Deposits which represent combinations of types 1 and 2, and which consist of lake, or pond peat, in the lower portion, and swamp, or sphagnum peat, above. These often resemble type 1 or 2 in appearance, and their true nature may only be ascertained by soundings.
4. Deposits which occur on flats and lowlands along river valleys.

ASSOCIATIONS OF PEAT-FORMING PLANTS.

Peat deposits may be divided into two main groups according to the type of surface upon which the peat accumulated. These are: (1) peat deposits formed in basins filled with water, and (2) peat deposits formed on flat, or gently sloping, undrained, land surfaces. The plant associations active in forming these two types of deposit are entirely different, especially in the earlier stages of development of the bogs. In order to clearly trace the origin of peat and the various developmental stages in the history of the peat deposits, the plant associations which are characteristic of these two types of bog should be considered.

Plant Deposits in Lakes and Ponds.

Peat bogs in coniferous forest regions go through the following developmental stages, if not arrested through the influence of some external agency.[6]

1. Stonewort—waterweed stage. (*Chara-Philotria* Associes.)
2. Pondweed—waterlily stage. (*Potamogeton-Nymphaea* Associes.)
3. Rush—wild rice stage. (*Scirpus-Zizania* Associes.)
4. Bog meadow stage. (*Carex* Associes.)
5. Sphagnum—bog heath stage. (*Andromeda-Ledum* Associes.)
6. Tamarack—spruce stage. (*Larix-Picea* Associes.)

In the deciduous forest regions the peat bogs go through essentially the same stages until the lake is filled with peat, when the

[6] Bergman, H. F., Department of Botany, University of Minnesota. Unpublished manuscript.

swamp plants are replaced by those of the climax vegetation, and the accumulation of peat is stopped.

In the prairie regions the swamp vegetation is never replaced by trees. Bog-heaths, tamarack, and spruce are never found. The swamp or bog-meadow stage is the highest stage attained by peat bogs of the filled-lake type in the prairie regions. The developmental stages preceding the swamp stage are the same as for the forested regions. When a prairie swamp fills up and becomes too dry for peat accumulations, the swamp vegetation, consisting chiefly of sedges, reed-grasses, etc., is replaced by the typical prairie grasses, such as blue-steam, Indian grass, and porcupine grass.

Peat Deposits on Flat, or Gently Sloping, Wet Surfaces.

A swamp represents an arrest in the natural development of the vegetation of a region. In the case of swamps derived from filled lakes, just described, they are arrested *primary successions.*[7] If the arrest in the vegetational development is caused by some outside influence, such as glaciation, flooding, forest fires, etc., a *secondary succession* may be initiated. Thus, any cause which destroys the existing vegetation of a region may start a secondary succession, and the secondary succession may begin at any point between the first stage and the climax vegetation. Peat bogs which have been built up on flat, wet, or flooded surfaces are secondary successions.

In Minnesota and throughout most of the Lake Superior region, where the largest and deepest bogs in the United States occur, there are many extensive swamps of this type. The chief agency which has initiated these secondary successions has been *glaciation.* The glaciation of this region completely destroyed all the existing vegetation. Upon the melting and recession of the ice, the drainage of the recently denuded surface was blocked, and large areas of flat or depressed land lying south of the retreating ice sheet were flooded, and temporary glacial lakes formed. Other large areas, while not covered with water and

[7] Bergman, H. F., unpublished manuscript, University of Minnesota.

converted into lakes, were kept constantly wet and marshy. Upon such surfaces as these the built-up peat bogs of the northern states have been formed.

The peat in many of these bogs consists chiefly of sedge and grass remains, showing that the deposit remained for a long period in the bog-meadow stage. In other bogs of this type the peat consists almost entirely of the remains of sphagnum, or peat moss, showing that this plant obtained a strong foothold among the first plants to appear after the recession of the ice, and that the development of the resulting bog was more or less permanently arrested in this stage.

Under ordinary conditions the swamps originating by secondary succession (built-up bogs) may pass through the same stages of development as those originating by primary succession (filled lakes), but the built-up deposits may start at any point in their development, and through the influence of certain outside agencies, they may be permanently arrested at any stage, so that only one or two typical plant associations will be represented in the bog. This is why there are so many large peat bogs in northern Minnesota which are built up on flat surfaces chiefly from the remains of a single plant species.

The commonest plant remains found in the peat deposits which have originated in this manner are those of sphagnum, sedges and grasses. These are never mixed in the same layers of peat. Oftentimes the peat in a given bog will consist almost entirely of sphagnum, especially in the coniferous forest region. In the prairie region, the peat in these built-up deposits consists almost entirely of sedges and grasses. Where both sphagnum and sedges occur in the same deposit the sphagnum always is found in layers overlying the sedge peat.

The plants now found growing on these built-up bogs are, in many cases, the same as those from which the peat in the deposit has formed. In other instances the bogs have passed into a more advanced stage, and plant associations of heaths and sphagnum, or tamarack and spruce are found growing on peat consisting mostly of sedge remains or layers of sedge peat, covered with

sphagnum peat. The largest built-up bogs in the coniferous forest regions of the north are now in the tamarack-spruce stage, or bog-heath-sphagnum stage. These built-up deposits, when in such advanced stages of development, cannot be distinguished from the filled-lake bogs by any surface indications. Their true nature can only be ascertained by the study of the plant remains in the peat, and by a careful determination of the character and topography of the bottom of the bog by means of numerous test holes.

As already pointed out, under certain conditions of water level, peat may be built up layer by layer on top of filled-lake deposits. These bogs may also show the same plant associations as those now growing on the surface and hence it is usually impossible to determine the history of any given bog in the northern part of North America from a casual inspection of the vegetation growing on the surface.

PHYSICAL AND CHEMICAL PROPERTIES OF MINNESOTA PEAT.

Color.

The prevailing color of Minnesota peat is brown. Dark brown predominates, while light or yellowish-brown is a common shade. The pond peat, composed of aquatic plants, is nearly always greenish, varying from yellowish-green to greenish-brown. In a few deep bogs, peat of a straw-yellow color was found near the bottom. All the peat, regardless of the color, turns a darker shade within a few minutes after being dug and exposed to the air. Black peat occurs in the bottom layers of some of the deposits, but only a few such instances were noted.

Texture.

The texture of the peat also varies greatly, and is dependent upon (1) the type of plants composing the peat; (2) the manner in which the deposit was formed; and (3) the degree of decomposition. The commonest texture in the Minnesota deposits is fibrous or mossy. The upper layers of all the deposits are dis-

tinctly fibrous. In some of the open sedge bogs the upper portion of the peat is spongy. The sphagnum peat is mossy. This fibrous or mossy peat extends downward for variable distances depending upon the types of plants composing the middle and lower layers of the deposits, and upon the amount of decomposition which has taken place. The bottom layers are often well decomposed, and the fibrous texture is destroyed.

Chemical Composition and Fuel Value.

The following table of analyses shows the chemical composition and fuel value of 29 samples of typical peat from northern

ANALYSES OF SOME PEAT SAMPLES FROM MINNESOTA.

(Analyses by United States Bureau of Mines.)

Locality. County.	Analysis No.	Locality No.	Moisture as Received.	Proximate.			Ultimate.					Thermal Value B. T. U.	
				Volatile Matter.	Fixed Carbon.	Ash.	Sulphur.	Nitrogen.	Hydrogen.	Carbon.	Oxygen.	Moisture.	Moisture and Ash Free.
St. Louis.	188	10	14.33	59.82	26.66	13.52	.29	1.63				7,862	9,091
"	189	11	12.65	60.82	26.01	13.17	.29	2.16				8,490	9,778
"	190	12	14.05	60.71	20.85	18.44	.52	1.65				7,466	9,154
"	191	18	14.58	65.73	23.97	10.30	.28	2.62				8,950	9,978
"	192	19	26.43	62.62	20.69	16.69	.24	2.26				8,289	9,949
"	193	20	14.53	64.96	25.04	10.00	.25	2.49	4.83	53.88	28.55	8,896	9,884
"	194	21	13.45	67.51	24.40	8.09	.24	2.58	5.23	53.24	30.62	9,153	9,959
"	195	21a	40.35	69.66	20.37	9.97	.34	2.35				8,899	9,884
"	196	22	12.48	66.64	24.79	8.57	.26	2.38	5.29	52.91	30.59	9,149	10,006
"	197	23	13.38	65.65	24.16	10.19	.18	1.93				8,698	9,685
"	198	24	24.00	66.22	23.45	10.33	.14	1.76				8,930	9,959
"	199	25	20.10	61.95	24.62	13.43	.29	1.68				8,150	9,415
"	200	26	16.73	61.63	22.94	15.43	.31	1.95				8,098	9,575
"	201	27	12.80	61.50	22.41	16.09	.31	2.68				8,403	10,014
"	202	28	14.20	64.25	23.77	11.98	.31	2.67				8,902	10,114
"	203	29	36.60	62.98	18.91	18.11	.25	2.03				7,953	9,771
"	204	30	9.83	63.62	24.07	12.31	.30	2.64				8,762	9,992
"	205	31	11.03	66.54	24.88	8.58	.26	2.69	5.33	52.41	30.73	9,056	9,906
"	206	32	10.78	74.17	22.60	13.23	.21	2.68				8,637	9,955
"	207	33	13.55	62.06	22.87	15.07	.22	2.73				8,351	9,832
"	208	34	16.83	63.91	24.01	12.08	.37	2.56				8,649	9,837
"	209	35	16.53	60.98	24.28	14.74	.29	2.34				8,409	9,863
"	210	36	40.35	65.72	21.04	13.24	.28	2.43				8,620	9,936
"	211	37	12.60	68.97	23.84	7.18	.21	2.17	5.42	52.93	32.08	9,265	9,983
"	212	38	10.20	63.81	27.92	8.27	.27	1.15	4.74	52.43	33.14	8,849	9,646
"	213	39	12.10	66.15	25.20	8.65	.23	1.75	5.12	53.44	58.50	9,146	10,012
"	214	40	11.63	60.15	23.84	16.01	.65	2.32				8,240	9,188
"	215	41	9.25	58.90	17.13	23.97	.37	2.62				7,949	10,456
"	216	41a	9.83	67.26	22.67	10.07	.40	1.80	5.25	52.17	30.31	9,057	10,072

Minnesota. The most noteworthy features of the analyses are the high average nitrogen content of the peat, and the comparatively low ash content, both of which indicate peat of excellent quality for fuel. The composition and fuel values compare favorably with those of peat from other regions both in the United States and in Europe.

Distribution and Quantity of Peat in Minnesota.

The peat deposits of Minnesota fall into three more or less distinct groups: (1) in the northern part of the state, the so-called "muskeg swamps," occur chiefly in Beltrami, Koochiching, St. Louis, Itasca, Roseau, Aitkin, Crow Wing, Cass, and Clearwater counties; (2) in the central part of the state, the largest and best deposits are in Anoka, Ramsey, Wright, Hennepin, Stearns, Sherburne, Isanti, Washington, Chisago, Millelacs, and Douglas counties; and (3) in southern Minnesota, principally in Blue Earth, Nicollet, Le Sueur, Rice, Scott, Carver, Dakota, Steele, Freeborn, and Waseca counties.

The only areas in Minnesota which do not contain peat deposits are: (1) the "driftless area" in the extreme southeastern part of the state; (2) an area in the Red River Valley in the extreme northwestern corner; and (3) a narrow strip along the boundary between Minnesota and North and South Dakota, on the extreme western edge of the state.

From the investigations made by the writer for the Minnesota Geological Survey, it is estimated that Minnesota had originally about 7,000,000 acres of peat land containing peat deposits varying in thickness from a few inches to 30 feet or more. Of this great area, about 5,217,000 acres are covered with peat at least 5 feet thick (the minimum workable depth). The total quantity of peat available for machine peat fuel of good quality in Minnesota, occurring in deposits 5 feet or more thick, estimated on a basis of 200 tons of air-dry machine peat per acre-foot of peat, is approximately 6,835,300,000 short tons.

If this peat were converted into machine peat bricks and sold at $3.00 per ton, it would have a value of $20,505,900,000.

The largest and best peat fuel deposits in Minnesota occur in St. Louis, Koochiching, Beltrami, Itasca, Aitkin, Carlton, and Roseau counties—all in the northern part of the state. There are many hundreds of smaller bogs scattered throughout nearly every county in central and northern Minnesota, most of which contain good fuel peat.

While most of the peat deposits are now too remote from railroads to offer immediate commercial possibilities, there are nevertheless hundreds of thousands of acres of peat fuel deposits of the highest quality which are crossed by railroads.

POSSIBLE USES OF MINNESOTA PEAT.

Peat Fuel.

One of the most important problems in northern Minnesota at the present time concerns the most profitable commercial use that can be made of the peat deposits of that region. It seems probable that the manufacture of power in peat producer-gas plants will soon be attempted, and there seems to be an unusual opportunity in Minnesota for success in that field, especially near the iron-mining districts. Such power has been successfully produced in a number of large plants in Europe, and there seems to be no reason why their success cannot be duplicated here.

There is also an attractive field in Minnesota for the manufacture of *machine peat* for domestic fuel.

Although there are no commercial plants for the manufacture of peat fuel in the United States at the present time, it is probable that the industry will develop in this country within a few years, as it has been developed to a high degree in Europe. A large experimental peat fuel plant was recently operated at Alfred, Ontario, by the Canada Department of Mines,[8] and after the manufacture of machine peat was proved to be commercially successful, the plant was taken over by private interests. Plate

[8] For descriptions of various types of peat machines, and peat manufacturing processes, see Bulletin 16, U. S. Bureau of Mines, and Publications 151, 154, 266, 299, Mines Branch, Canada Department of Mines.

XXXIV. shows two views of the Ontario peat fuel plant. The peat used at the Ontario plant was identical in quality with that found at numerous localities in northern Minnesota.

Modern peat fuel is made by special machinery and the product, which is put on the market in the shape of blocks, or bricks, similar to stove wood in size, shape and weight, is called *machine peat*. This is the type of peat fuel which has proved to be a commercial success in Europe and in Canada, and which will probably form the basis of any peat fuel industry which may develop in this country in the future.

Numerous plants have been built to manufacture peat briquettes but none of these attempts have as yet proved to be commercially successful. The chief difficulty to be overcome seems to be the high cost of eliminating the moisture from the raw peat by any method of artificial drying. Machine peat is dried in the sun.

By-Products from Manufacture of Producer-Gas.

The principal by-product which can be obtained from the manufacture of producer-gas is ammonium sulphate $(NH_4)_2SO_4$, which, because of its high nitrogen content, is in great demand as a fertilizer. Theoretically, 1 short ton of dry peat containing 1 per cent. nitrogen will yield 94 pounds of ammonium sulphate. In the European plants the recovery is about 75 per cent., *i. e.*, approximately 70 pounds of ammonium sulphate are produced per short ton of peat burned, calculated on a moisture-free basis.

Agricultural Uses of Peat.

The possibility of using the large tracts of shallow peat land in northern Minnesota for agriculture is of the greatest importance, and the industrial future of several entire counties in the northern part of the state depends to a large extent upon the uses which can be made of the peat deposits there. Already a large acreage of peat land is under cultivation. The results of experiments made in this country and at European peat experiment stations show that peat soils will produce satisfactory

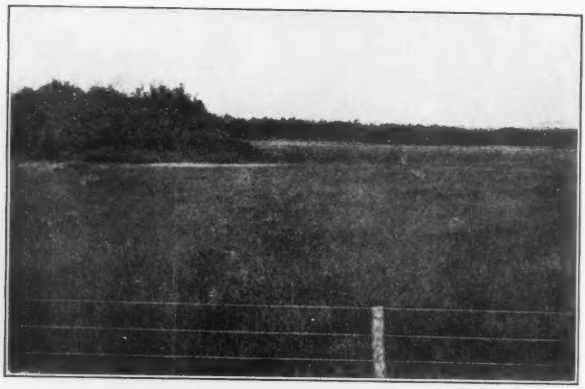
EXPLANATION TO PLATE XXXI.

A. Looking along drainage ditch through a typical tamarack swamp of northern Minnesota. Peat is two to seven feet thick. Note plat spread out for road-bed.

B. View along newly constructed road through dense black spruce swamp, northern Minnesota. Peat is about five feet thick.

A

B



A

B

EXPLANATION TO PLATE XXXII.

A. Peat deposit of the filled lake type, northern Minnesota. Note the old shore line. Peat is four to ten feet thick.

B. View along drainage ditch through big open peat bog in northern Minnesota with tamarack zone in the distance. Note the peat on the spoil bank of the ditch, which is levelled off for a wagon road. Peat is seven to twenty feet thick.

EXPLANATION TO PLATE XXXIII.

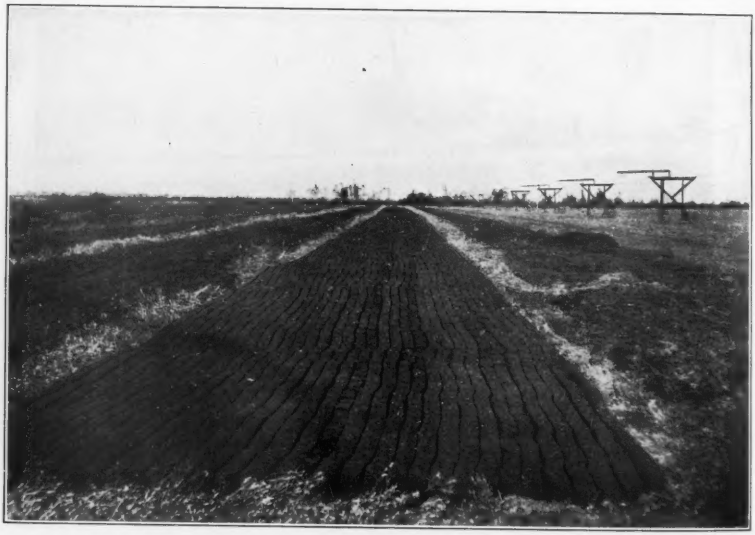
A. Pond-lily and sedge zones around peat-forming lake in Itasca County, Minnesota.

B. Zones of bulrushes and giant sedges around border of a peat-forming lake in southern Minnesota. Note floating mat of vegetation in immediate foreground.

A

B

A



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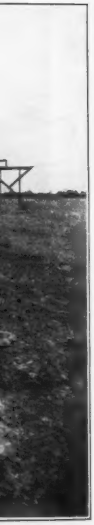

EXPLANATION TO PLATE XXXIV.

A. Peat machine (Moore System) in operation at Alfred, Ontario. (Photo by E. V. Moore.)

B. View showing method of spreading and drying machine peat on the bog (Moore System) at the Alfred plant, Alfred, Ontario. The row on the left has been cross cut into blocks, while the row in the center has just been spread. Note peat machine in the distance and trolley for operating spreader to the right. (Photo by E. V. Moore.)

crops of forage plants, small grains, and all ordinary vegetables except asparagus, with proper cultivation, and fertilization. There are, however, certain limitations upon the profitable cultivation of peat bogs.[9] These are: (1) drainage, (2) depth and character of peat, (3) climate, (4) transportation facilities, and (5) expense of marketing the products.

Other Uses.

The possibility of using peat in the iron-ore industry of Minnesota has been suggested by Professor Peter Christianson, of the Minnesota School of Mines. The possible applications, as suggested by Professor Christianson, are: (1) the use of peat for power; (2) the use of peat for heating operations in drying, roasting, sintering or calcining; (3) the use of peat as a binder in ore briquetting; and (4) the possible use of peat coke or charcoal in smelting.

Peat is extensively used in the United States as a fertilizer filler, in which capacity it is said to improve the fertilizer both chemically and mechanically. It is also used in this country to a considerable extent for stable litter and packing material. The fibrous and mossy peats of Minnesota would be especially suitable for such uses. Other uses for peat are: for paper stock, woven fabrics, ammonium compounds, artificial wood, manufacture of nitrate, dye stuffs, materials for tanning, and sanitary and medicinal uses.

[9] "Limitations on the Cultivation of Peat Lands in Minnesota," F. J. Always, *Journal American Peat Society*, April, 1916, p. 65.

DISCUSSION

This department has been established by the editors in order to afford to those interested in questions relating to economic geology an opportunity for informal discussion. Contributions are cordially invited either in the form of discussion of more formal papers appearing in earlier numbers or bearing upon matters not previously treated. Letters should be directed to the Editor, Sheffield Scientific School of Yale University, New Haven, Conn. The full name of the author should be attached to all communications.

PHYSIOGRAPHIC CONDITIONS AND COPPER ENRICHMENT.

Sir:—The interesting article by Professor W. W. Atwood on "The Physiographic Conditions at Butte, Montana, and Bingham Canyon, Utah, when the Copper Ores in these Districts were Enriched," as published in a recent number of this journal, represents one of the few attempts that have been made to correlate physiographic history with the development of metallic veins. As stated by the author, it was preceded several years ago by a somewhat similar article by Mr. J. B. Umpleby, regarding a district in central Idaho. Although addressed primarily to economic geologists, Mr. Atwood's paper raises anew an old question that has been discussed for years by S. F. Emmons, Powell, Willis, Daly, Lindgren, Calkins, and others—the ages of the existing features of Rocky Mountain topography. On reading this latest contribution one is likely to miss the essential fact that this is distinctly a debatable and indeed debated group of questions. I therefore avail myself of the well-appreciated opportunity offered by the "Discussion" column of this journal, to point out some of the consideratoins on the other side of the controversy.

During some ten or twelve field seasons in the Rocky Mountains, including districts immediately adjacent to those discussed

by Mr. Atwood, I have studied many of the same phenomena, but have reached different conclusions on several points. Some of these questions I have already discussed in print elsewhere,[1] but since many readers of ECONOMIC GEOLOGY may not have seen the articles, it may be well to restate here very briefly those considerations which apply to the case in hand.

From his observations Mr. Atwood was led to agree with some of his predecessors that the tops of many mountains in western Montana and central Idaho represent an ancient peneplain, and that this plain was cut during the Eocene period. Granting the existence of the peneplain, it seems to me that the Eocene age of it is far from satisfactorily established. The evidence given by Mr. Atwood in supoprt of this hypothesis is that there are broad deep-branching valleys below the peneplain level, and that these valleys are now partly filled with Oligocene and Miocene sediments. Perhaps he omitted some pertinent facts bearing on these questions. At any rate I find nothing in his paper to indicate that he considered two other possibilities, viz.: (*a*) that the Tertiary deposits were folded or faulted downward below the base-level of erosion, and among masses of harder rock; that this mosaic was afterward planed off, and that the broad valleys were subsequently excavated on the outcrops of the Tertiary formations solely because of their relative weakness; or (*b*) that early in the Tertiary period these valleys were excavated, were afterward filled with Oligocene and Miocene sediments and the entire region was thereafter reduced to a peneplain at a level considerably above the bottoms of the original valleys, but below the tops of the aggradation plains. I think it must be admitted that either of these chains of events (or some combination or variety of them) would have brought about conditions similar (although not identical) to those described by Mr. Atwood. These hypotheses are illustrated by the diagrams, Figs. 20, 21 and 22.

[1] "The Old Erosion Surface in Idaho: a Criticism," *Jour. of Geol.*, Vol. XX., 1912, pp. 410–414.

"Post-Cretaceous History of the Mountains of Central Western Wyoming," *Jour. of Geol.*, Vol. XXIII., pp. 193–207.

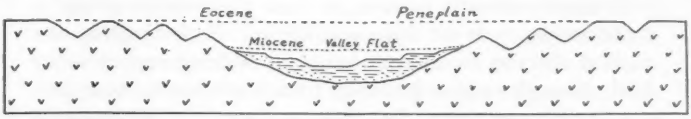

FIG. 20. An Eocene plain cut across folded Cretaceous and older rocks. Later broad and deep valleys were excavated and then partly filled with Oligocene and Miocene sediments. In still more recent time streams have partly dissected the filling. (Essentially Mr. Atwood's conception.)

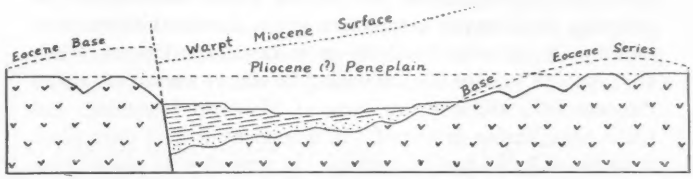

FIG. 21. An early Tertiary surface, either plain or hilly, on which a thick series of Tertiary sediments was deposited. Afterward the region was gently folded and faulted so that the Tertiary beds were left alternately above and below base-level. In post-Miocene times a period of comparative quiescence permitted the cutting of a plain over the entire district, but some of the weak Tertiary deposits were preserved because they were far below base-level. In consequence of a later uplift streams rapidly excavated and planed the Tertiary deposits down to a new base-level and at the same time carved canyons and ravines in the harder rocks adjacent.

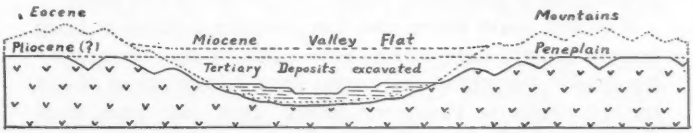

FIG. 22. A broad, deep valley was excavated early in the Tertiary period and then more or less completely filled with Oligocene and Miocene deposits. The region was thereafter reduced to a peneplain, but a part of the Tertiary deposits were so far below base-level that they could not be removed. Subsequent rejuvenation of the region permitted the streams to intrench the Tertiary beds quickly and reduce them to a new plain, while the harder rocks adjacent were carved into mature topography with occasional remnants of the peneplain. On this hypothesis deformation of any kind is eliminated.

It is not necessary, however, to leave the question of age in doubt among three or more possibilities. Both Umpleby and Atwood describe the summit peneplain as being approximately level, although varying gradually from 6,000 feet to 8,000 feet, and in Idaho to 10,000 feet above sea-level. It can be reconstructed, according to Mr. Atwood, by "lifting certain tilted blocks, straightening out some warped surfaces and filling the great intermontane troughs in the old peneplain" (page 707). It appears, however, that these places of warping and faulting are somewhat exceptional, and on the whole remnants of the peneplain stand nearly everywhere at the elevations above mentioned. On the other hand the early Tertiary sediments, which are supposed to have been deposited in valleys excavated out of the peneplain, are in many parts of Montana, Wyoming, and Idaho considerably deformed. It is common to find them tilted at angles of 5, 10, and 15 degrees. In a number of places folds with dips ranging from 25 to 50 and even 80 degrees have been found. In many places the beds have been broken by faults, and of these some have displacements of as much as 10,000 feet. Some of these facts are stated in Mr. Atwood's paper, but there are many more instances in print. It is difficult to see how any Eocene peneplain could retain an approximately horizontal attitude and nearly uniform elevation over a large part of two or more states, while sediments that have been subsequently deposited upon it were tilted, folded, and faulted to this extent.

It is well worth noting also that abundant evidence is being brought to light from time to time indicating that the existing topographic features of large areas have been produced almost entirely within the Pleistocene period. Such facts come from California, the Rockies, the Colorado plateau, Alaska, the Alps, and from many widely scattered regions over the globe. Indeed, on such general grounds it may fairly be doubted whether there is anywhere in existence a topographic feature as old as the Eocene and perhaps not older than the Miocene, excepting, of course, such ancient topographies as have been recently exhumed by the removal of later deposits.

These considerations lead me to think that the peneplain not only is not proven to be of Eocene age, but that the evidence is rather in favor of believing that it was carved after the mild deformative movements which followed the deposition of the Miocene sediments. In this connection it is significant that during the last twenty years peneplains of post-Miocene age have been reported from many other parts of the Cordilleran province by such men as Willis, Ball, Huntington, Davis, Robinson, Ransome and even by Mr. Atwood himself.

Therefore, while it is possible that an Eocene peneplain exists in western Montana and vicinity, the presumptions are against it, and we have a right to demand of its advocates more convincing evidence than they have yet presented.

ELIOT BLACKWELDER.

PHYSIOGRAPHIC CONDITIONS AND COPPER ENRICHMENT.

Sir:—Mr. Blackwelder has kindly submitted to me the above statement and asked that I have my reply appear, if possible, in the same number of your magazine.

The question at issue is the age of the summit peneplain in western Montana and eastern Idaho, adjoining the district studied by Mr. Blackwelder in Wyoming. I regret now that I did not treat this question more fully, and debate the alternative hypotheses which Mr. Blackwelder has urged, and which I considered while at work in the field.

In Mr. Blackwelder's figure No. 26 he has shown what is essentially my conception of the physiographic evolution. It should be remembered, however, that the troughs in which the Oligocene and Miocene sediments rest were not developed so much by stream erosion as by the warping and faulting of the peneplain. In considering the alternative hypotheses I should like to make the following points:

1. If the Oligocene and Miocene sediments were present at the peneplain horizon before the faulting and deformation by warping took place, should not some one of us who have been at work

in this portion of the Rocky Mountains have found remnants of those sediments upon that peneplain surface?

2. I found no evidence, in the region I examined, indicating that a peneplain had been developed upon the surface of the Oligocene and Miocene sediments. Such evidence should, I believe, be present if the peneplain is of post-Miocene age. Mr. Umpleby has reported that lake-shore features cut during Miocene times about the margin of Miocene deposits yet remain. This would not be so if the region examined by him had been peneplained after the close of the lake period.

3. The deformation of the Tertiary sediments is granted, as Mr. Blackwelder states, in my paper, but this deformation came, I believe, in association with a late Tertiary period of mountain growth when, through arching and renewed faulting, the mountains of today received essentially their present elevation.

4. The field evidence which I think will be most helpful in this whole discussion, and which I may not have called sufficient attention to in my article, comes from the distribution of the Oligocene and Miocene sediments, shown in Fig. 52, page 710, of my original article. The Tertiary sediments involved in this problem rest not only in the intermontane troughs, but, in a number of instances, they cross the mountain ranges where they rest in passes cut several hundred feet below the even crest line of the mountains. I would refer to localities Nos. 23, 26, 27, 31, and 32, in Fig. 52 of the original article. In Fig. *A* of Plate XXXIV. in the original article a view of Beaverhead Range from the southwest is shown. The crest line is a portion of the old summit peneplain. A little to the right of the center is the pass now used by the railroad and located where the number 26 is on Fig. 52. The Tertiary sediments rest at higher and higher elevations on the two sides of the mountains until they partially fill the pass. In this pass these sediments are at least 200 feet thick, and have very evidently been uplifted in the late Tertiary period of mountain growth when this range attained its present altitude. They rest in a saddle, astride the mountain range. The pass in which these sediments are is certainly an old stream

course through this range. The base below the Tertiary sediments is at least 500 feet below the old summit peneplain which appears at either side of the pass in the crest of the range. Was not the notch cut after the uplifting of the peneplain and before the Oligocene and Miocene sediments which rest in it were deposited? Therefore, is not the age of the notch pre-late Oligocene? The peneplain was uplifted before the notch was cut, and it was certainly developed before it was uplifted, therefore, I again come to the conclusion that the peneplain in the region I studied must be pre-late Oligocene, and I believe it was developed by the close of Eocene time. This is not an isolated example. Remember, there are five similar cases within the region studied, and I see no way to avoid that sequence of events in the physiographic history and that geologic dating of the age of the summit peneplain.

I take pleasure in agreeing with Mr. Blackwelder in the belief that our relief features in the Cordilleran provinces of North America are exceedingly young. I hope others will believe that certain peneplains that I have described are of very late Tertiary age. I believe that most of the great canyons in our western mountains and high plateaus have been excavated during and since the Pleistocene time. However, I am not convinced that there are no topographic features in existence as old as the Eocene sediments, and the more I think of the physiography of the western portion of the continent, the more firmly I believe that there has been variety in the relief of that portion of the continent throughout post-Cretaceous time. I have given up the thought that there was one period of widespread peneplanation when the entire Cordilleran region was near to base level, and now favor the working hypothesis that while certain regions were high, others were low, and the relief has been different in degree, yet of the same general type that we now have in the Cordilleran provinces.

WALLACE W. ATWOOD.

GENESIS OF SUCCESS ZINC-LEAD DEPOSIT.

Sir:—In the February–March number of your journal, Mr. J. B. Umpleby discusses the "Genesis of the Success Zinc-Lead Deposit, Cœur d'Alene District, Idaho." The article was evidently intended as a refutation of certain allegations made in my last Cœur d'Alene paper,[1] which it treats with entire courtesy, and the writer hopes that it will be understood that his intentions are to be as complimentary in return. Fully accepting Mr. Umpleby's microscopic work as the last word possible in that line, yet, after reading the paper several times, a feeling of uncertainty on some points remains, and the writer takes the liberty of again presenting his view, now modified by facts established by Mr. Umpleby.

Mr. Umpleby draws three principal conclusions as follows: "(1) the deposit is of contact metamorphic origin, differing only from most deposits of this type in that the metamorphosed rock is siliceous slate and quartzite instead of limestone; (2) the metamorphism took place, at least in large part, after the solidification of the igneous rock adjacent which is locally replaced by metamorphic minerals, and (3) a poorly defined zone of shearing, which accompanies a biotite schist member of the Prichard formation, directed the metamorphosing solutions." As evidence that the ores are a little younger than the monzonite he states that: "(1) pyrite and sericite, minerals intimately associated with the sulphides, are extensively developed in the monzonite, the former principally after hornblende and the latter after feldspar; (2) sphalerite, galena, magnetite and lime silicates intergrown with them, replace the monzonite in several places; (3) the same sulphides occur as veinlets in monzonite in at least five other deposits of the district, and (4) the ore bodies in places traverse dikes of the monzonite as on the 300-foot level."

The first point on which I wish to take issue with Mr. Um-

[1] Hershey, O. H., "Origin and Distribution of Ore in the Cœur d'Alene." Published at private expense by *Mining and Scientific Press*, San Francisco, Cal., 1916.

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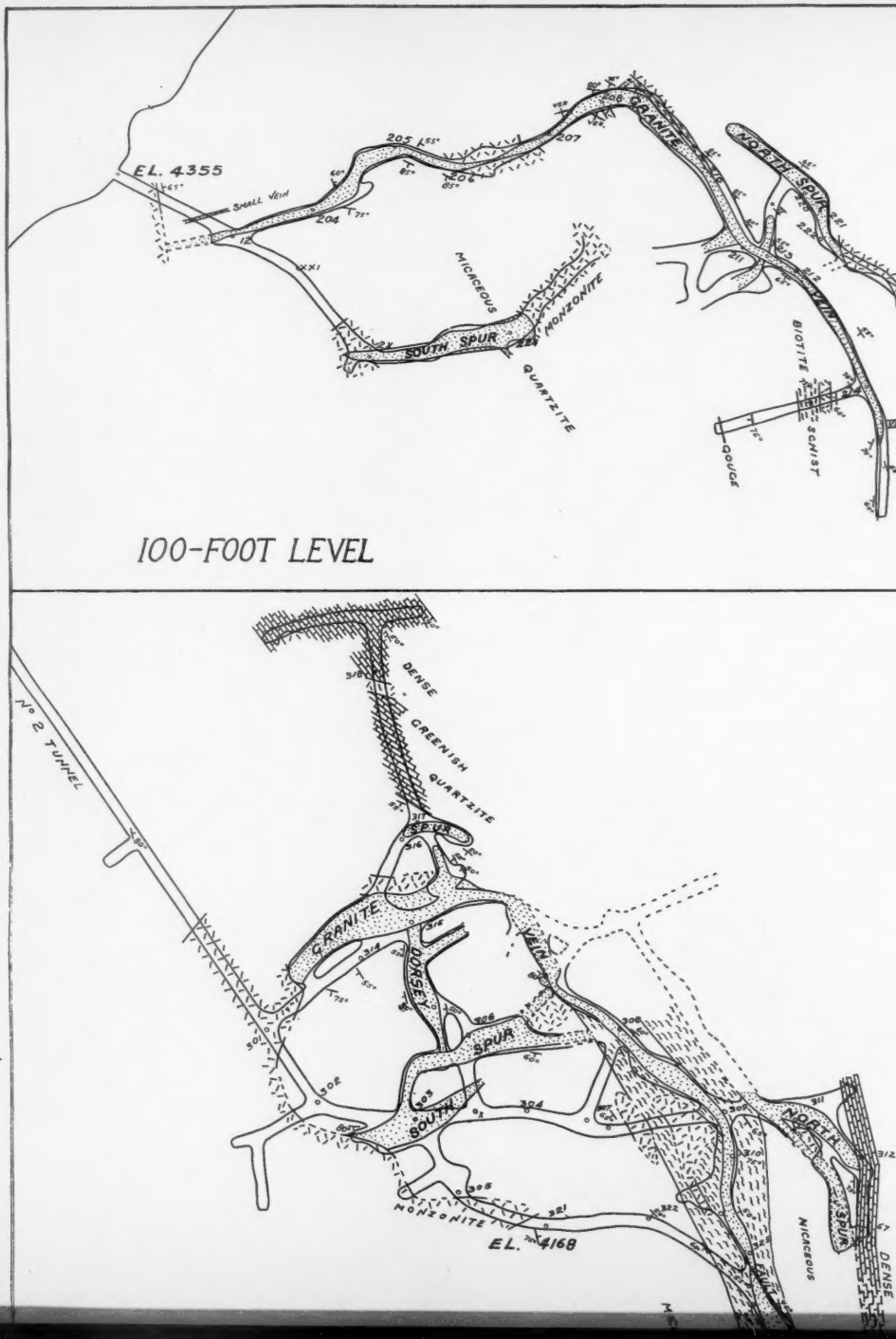
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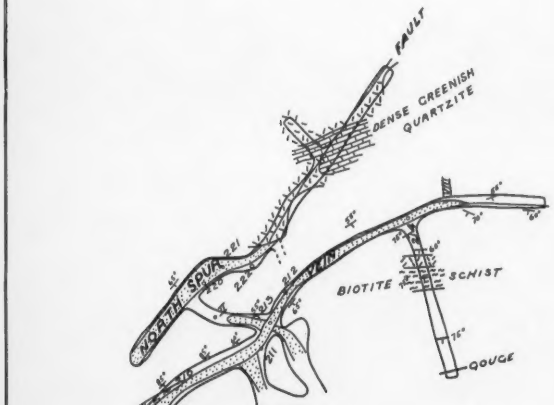
FAULT
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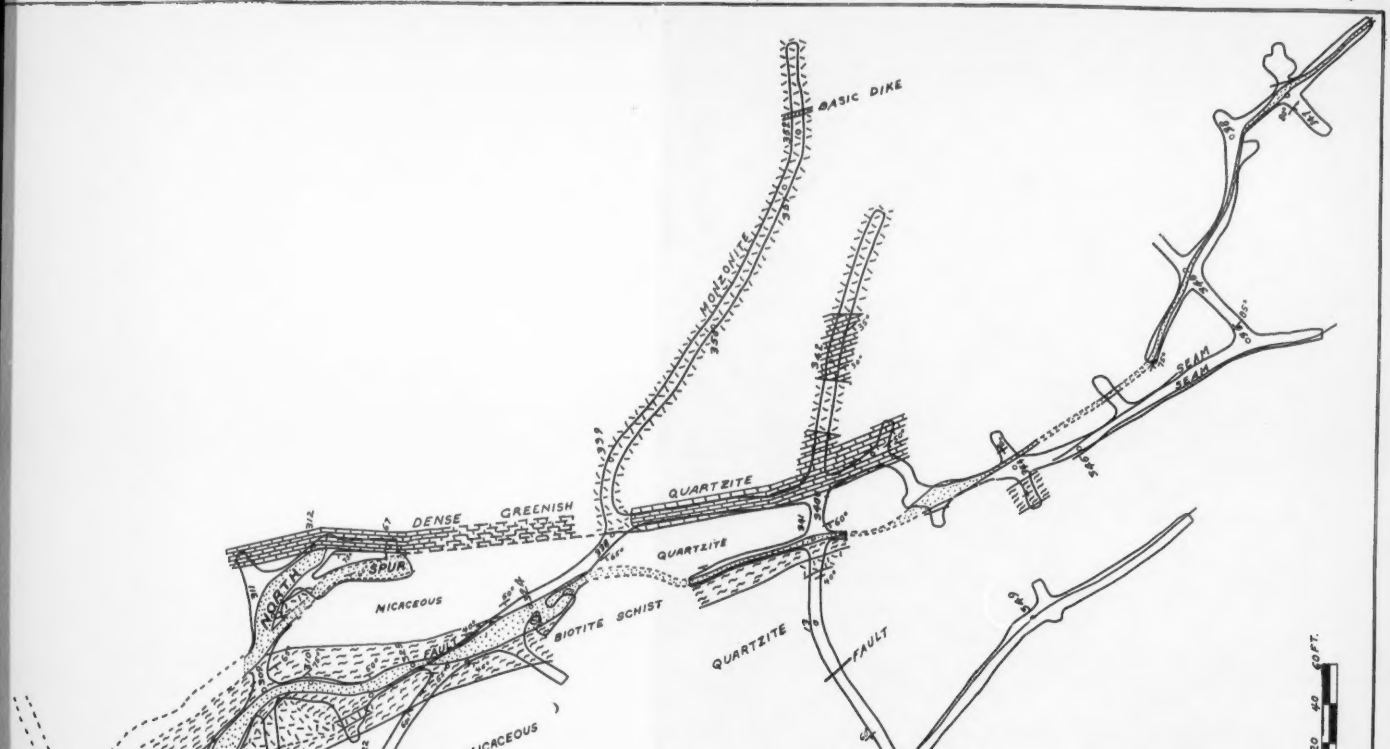
FIG. 23.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IG. 23.

pleby is as to the rôle played by the biotite schist in the distribution of the ore. He says that "of the several types of rock in the mine, most of the ore is inclosed in mica schist, a notable amount in the micaceous quartzite, very little in the dense greenish quartzite, and still less in the monzonite." He attributes the distribution of the ore, not to localization in connection with a fissure system, but to "selective replacement along the course of a particular type of rock, the biotite schist." "Along this course there is no evidence of fissuring, but instead a distinct schistosity, perhaps accompanied by some shearing, parallel to which most of the ore lenses are oriented. Wider parts of the ore bodies in many places extend beyond the limits of the biotite schist into the micaceous quartzite above and below, and locally lenses of considerable size occur many feet beyond the limits of the schist."

I divided the metamorphosed sediments into a fine-grained greenish and white quartzite band (50 feet thick) on the northeast, the rock denominated by Mr. Umpleby as dense greenish quartzite; a quartz-schist band 40 to 70 feet thick; a band of dark-gray mica-schist 10 to 15 feet thick; and finally 200 feet of quartz-schist. Mr. Umpleby uses the term micaceous quartzite instead of quartz-schist and biotite schist instead of dark-gray mica-schist and I will adopt his terminology. The position of these bands is indicated in sketches of the 100-foot and 300-foot levels of the mine (Fig. 23).

In the 100-foot level sketch I have mapped the longest practically continuous ore body as the Granite vein, it being the discovery vein of the Granite claim. This is in two segments, each about 250 feet long, that make an angle of about 110° with each other. The southeast segment is nearly parallel with the quartzites and schists, cutting them at acute angles and dipping southwestward 70° to 85°. It has been stoped nearly continuously either above, on or below the level to about station VIII. Beyond that it is reduced to a small fissure with a thin gouge in 2 to 6 inches of sheared rock along which there is limonite and a few small lenses of vein quartz with green chlorite-like aggre-

gates and some pyrite, galena and sphalerite. The other segment of the vein has a course about S. 75° W. and is nearly vertical. This segment of the vein cuts the metamorphosed sediments at high angles. The rock on the south side strikes southeast and varies from vertical to a southward dip of 75°. Much of the rock on the north side strikes south to southwest and dips east to southeast 55° to 65°, making this segment of the vein follow a pronounced fault fissure. The same marked discordance between the strata on opposite sides is present at the surface. It gradually dies out with depth and is not a prominent feature as low as the 300-foot level. My impression is that the stress that produced the faulting tended to cause breaking along east-west lines, but when the major fissure reached the biotite schist band (or siliceous slate of an earlier stage) it was deflected along it and became practically a strike fault. This fault is the cause of a marked variation in thickness of the band on the various levels, partly cutting it away on some and partly repeating it on others. The two segments of the Granite vein may be found on all the levels down to the 1,000-foot; but the western segment is shortened with depth by the encroachment upon it of the main mass of the monzonite. Even in Mr. Umpleby's sketch of the 300-foot level it cuts obliquely through the schist band as though developed along a fissure.

On the 100-foot level the North spur goes off as a small sphalerite streak. This is doubtless soon interrupted by the same monzonite arm that cuts it in the North Surface tunnel. Beyond this monzonite arm the North spur has been extensively stoped in the drift that contains station 221. Here it, also, has swung southeast nearly into parallelism with the banding of the rock. Beyond station 222 it seems to be cut off by another arm of the monzonite. On lower levels the North spur clearly connects, at its west end, with the main vein. It usually starts off at the bend in that vein at a high angle to the schists, curves to the right in the lower band of micaceous quartzite and on some levels apparently ends near the dense greenish quartzite. On others it swings back toward and reunites with the southeast

segment of the main vein. It is clearly recognizable to the 700-foot level, but deeper may entirely merge with the main vein. It does not represent a strong fissure and the fracturing was unable to penetrate the dense greenish quartzite band. That is my explanation of the almost total absence of ore in that type of rock. The mineral-depositing solutions could not extensively replace it because the fractures were lacking to carry the solutions into it.

At station 211, on the 100-foot level, the stope on the Granite vein opens into that on one prong of the South spur. The portion of the South spur that includes stations 2X and 224 has been mined in a stope that is nearly vertical and connects with stopes on levels above and below. It terminates at the west end against the main mass of the monzonite and east of station 224 against a large arm of monzonite. This arm interrupts the South spur at the surface. This interruption does not occur on the 300-foot and lower levels, but the spur goes off from the main vein in places nearly at a right angle, in others obliquely, and extends 100 to 220 feet mainly through the upper band of micaceous quartzite to the main monzonite contact. Nearly everywhere it cuts the schistosity and the original bedding at high angles. It is exceedingly difficult for me to understand how the selective action of any type of rock produced this definite band of ore cutting the structure planes to a considerable extent nearly at a right angle, but I can readily see that a fracture practically parallel to the fault fissure followed by the western segment of the main vein would furnish the locus for the spur.

Several other short spurs have been recognized. The Peterson spur has been mapped on the 100-foot, 400-foot and 450-foot levels, and the Dorsey spur on the 300-foot, 400-foot and 450-foot levels. About 10 feet north of the Granite vein at station 12 on the 100-foot level, there is a small vein of sphalerite, galena and pyrite dipping southerly 70°. This may be a small independent vein or, on some other level, it may be a spur from the main vein. Near station 337 on the 200-foot level a small spur goes off northwest from the North spur. This is repre-

sented on the 300-foot level by a stope at station 317. On the 450-foot level a very weak development of vein matter appears northeast of the North spur. Near station 2 on the 700-foot level there is a small vein back of the main system. These are all the occurrences of ore noted by me in the winter of 1914–15, not clearly referable to the main Granite vein and the North, South, Dorsey and Peterson spurs. The ore minerals are not indiscriminately scattered throughout a large body of metamorphosed sediments, but are distributed along relatively narrow zones.

The vein and spurs as mapped by the writer include all the commercial ore. I do not say that there are no isolated seams of sphalerite and galena outside of the limits mapped, but that they are rare. Usually the drifts and stopes are a little wider than the ore and practically no mineral appears in the walls of these openings. Where an appreciable amount of mineral was observed in a wall, the vein mapping was carried into it. This is an important point for, without realizing that the country not included in the vein system as mapped is essentially barren, one might think the alleged vein and spurs merely represent the pay streaks in a large body of mineralized rock. On the contrary, so far as the essential ore minerals are concerned, the Granite is a discrete vein, as much so as any other in the Cœur d'Alene district.

In all veins in this district, the thickness and degree of mineralization vary constantly both horizontally and vertically. On one level an ore-shoot may be a large body whose removal leaves a chamber like a room in a cave and on another level it may be a long narrow streak of ore. Some of the shoots of mineral may be minable at a profit only in their swells, giving the impression of isolated lenses of ore. In the Success mine the larger shoots have been unusually persistent, some probably having been mined continuously, except for sections not yet stoped at the time of my study, to depths of 700 to 1,000 feet. Therefore, Mr. Umpleby's remarks about the lenticular character of the commercial ore, if intended to convey the idea that the deposit is unique, do not appear to me conclusive.

With the exception of minor details in generalizing the geology between mine openings, my field observations call for a modification of Mr. Umpleby's map of the 300-foot level as follows: The North spur should not be broken near station 311 by monzonite and barren quartzite; the South spur should be connected with the main vein on the basis of a caved stope; the South spur should be connected through from station 306 to 303, at least with dotted lines, because it can be seen going into the wall at 306, is hidden by timbering at the winze or raise near 303 and no such interruption occurs on higher and lower levels; the Dorsey spur should be connected with the main vein at one end and the South spur on the basis of a closed stope at the other end; the main vein should not be broken at station 300 (309) nor at 325 except for a little faulting; it should not be broken at station 324; the sporadically mineralized shear zone should be carried through by stations 341, 344, 346, near 38, and by 347 to the face; finally, I have seen no justification for carrying the main monzonite area across the drift at 346.

Mr. Umpleby's chief objection to the writer's use of the term vein seems to lie in a belief that the mineralization was not related to fissuring of the rocks, but to selective replacement along the course of the biotite schist, but the evidence seen by the writer warrants, he hopes, a repetition of his assertion that "the ore is in a vein and spurs" and that the main fissure in "general character" "is like the fissures of the Prichard type veins at a distance from the granite."

The term vein is used as it is commonly applied in the Cœur d'Alene region, namely, to a body of mineralized rock that is very much longer and deeper than broad. The presence or absence of contact metamorphic silicates does not affect the propriety of the use of the term. The writer certainly would not like anyone to deny him the privilege of applying the term vein to the Banner and Bangle ore deposit near Troy, Montana, a deposit which is several thousand feet long, many hundred feet deep, but scarcely anywhere over 10 feet wide, merely because it abounds in garnet and other contact silicates.

The second point on which the writer would take issue with Mr. Umpleby is that there is conclusive evidence that ore-bodies traversed monzonite apophyses. He relies chiefly upon certain places where stopes have monzonite in both walls. I would concede the pertinence of the evidence if the monzonite dikes had a regularity comparable with that of the basic dikes of the region. However, these are the facts: The intrusion has been exceedingly intimate. Irregular, branching monzonite dikes follow the main fissure and the North spur throughout much of the mine. No attempt has ever been made to correctly map them as it would require a very large scale map and many weeks. In view of this irregularity, the mere fact of a stope being bordered by monzonite does not prove convincingly that the monzonite ever extended across the space now occupied by the stope. The ore has been removed and we guess differently as to what gangue it contained. I may remark, incidentally, that the case is different where one can *see* a monzonite dike interrupting an ore zone.

Mr. Umpleby has clearly shown two stages of metamorphism. In the first stage the sediments were completely recrystallized, with the production of biotite, muscovite and the schistosity of the rocks. This antedated the intrusion of the monzonite that we see today. The faulting present on the 100-foot level was probably subsequent to this first stage of metamorphism, but the fault blocks are so embraced by the monzonite as to prove that the fissure is older than the intrusion of the adjacent monzonite. It is possible that the deposition of sphalerite and galena followed immediately upon and was incidental to the formation of the fissure system. In the second stage of metamorphism, sericite, garnet, pyroxene and epidote became distributed in irregular bunches, veinlets and ill-defined patches connected by stringers of similar material. This stage of metamorphism was closely connected with and in fact partly subsequent to the solidification of the peripheral portions of the adjacent monzonite. The ore minerals are to a considerable extent intergrown with the contact silicates of this stage. In fact, Mr. Umpleby shows that in

places sulphides and contact silicates occur in the monzonite. The amount of sphalerite and galena in the monzonite is less than one hundredth of one per cent. of the amount in the mine, but it is sufficient to yield material for a number of thin sections. That ore minerals may occur in places in the monzonite was recognized by me in my field study in the winter of 1914–15. This gave rise to the statement in my last paper that "in many places the monzonite has a little disseminated pyrite and in a few places I have suspected the presence of a small amount of disseminated sphalerite and galena in a sort of indefinite border zone a few inches thick at the contact between the monzonite that follows the veins and the ore." This I attributed to absorption by the intruded monzonite. The mere mixture of ore minerals, contact silicates and monzonite minerals would not be incompatible with my original idea, but Mr. Umpleby's statement that such aggregates contain "residual masses of the monzonite minerals" compels me to recognize that there was deposition of a certain amount of sphalerite and galena subsequent to the marginal solidification of the monzonite. In this matter of clearly, and I hope permanently, fixing the relation between the metamorphism and the monzonite intrusion, Mr. Umpleby's work is a great addition to our knowledge of the geology of the Success mine.

The writer is, however, not yet convinced that there are no inclusions of sphalerite with fragments of schist attached in the monzonite. He observed these alleged inclusions questionably at station 19 in the North Surface tunnel, and distinctly near stations 206 and 2X on the 100-foot level and near the end of the South spur on the 700-foot level. Of course, if Mr. Umpleby has cut thin sections from the most prominent of these supposed inclusions and they demonstrate that the material contains shreds of monzonite minerals and that the quartz is subsequent to the monzonite, it will weaken my case, though all it will prove is that I have been mistaken about the supposed inclusions.

The presence of sulphides as veinlets in monzonite or syenite at the American prospect, the Clark mine, the Frisco mine, the Lilly prospect and the Nellie Pollar prospect, cited by Mr. Um-

pleby, has no direct bearing on the matter at issue unless it can be shown that these sulphides are of the same age as those in the Success mine. Deposition of sphalerite and galena may have occured in this region at different periods and to use the above occurrences merely as corroborative evidence one must show what period they represent.

Mr. Umpleby also advances the argument that the Success ores are a little younger than the monzonite because "pyrite and sericite, minerals intimately associated with the sulphides, are extensively developed in the monzonite, the former principally after hornblende and the latter after feldspar." The writer must acknowledge that the point of the argument escapes him. Pyrite has been deposited in the Cœur d'Alene district at different periods and under a variety of conditions. Sericite is a mineral widely distributed in the district. Does its presence as an alteration product of the monzonite and as a nearly universal constituent of the sedimentary rocks of the Cœur d'Alene district prove that it was not developed in the sediments until after the monzonite intrusion? To give the argument strength Mr. Umpleby should show that the pyrite and sericite rather widely distributed in the monzonite and present in the Success ore are of peculiar and unusual types, not developed under other conditions in the Cœur d'Alene. But, granted that the pyrite and sericite in the monzonite and ores are of the same age and origin, they do not prove more than has already been better proved by the interlocking of sphalerite and galena with the contact silicates.

Now let us look at the other side of the question: The contact metamorphic silicates that represent the second stage of metamorphism are very widely distributed in the tongue of Prichard sediments. "The rocks are more intensely metamorphosed in the east end of the mine than elsewhere but most of the ore occurs in the west end." "Garnet is most abundant in the fine-grained, greenish quartzite which occurs principally in the eastern part of the mine. Sericite is conspicuously developed in the micaceous quartzite above and below the schist and to a less extent in the other rocks. Diopside occurs principally in the biotite schist. Tourmaline appears in one of the slides of green-

ish quartzite." In other words, the contact silicates of the second stage are very differently distributed from the ores. Sphalerite and galena are very local in comparison with the contact silicates. Mr. Umpleby's conclusion that the ores are "due to magnatic emanations which escaped, in large part at least, after the marginal solidification of the magma," and the whole tenor of his argument based on the interlocking of the ore minerals and contact silicates imply that the sphalerite and galena were brought out of the monzonite by the gases or water that brought part of the constituents of the contact silicates. In that case, why is there such a radical difference in their distribution? Why did not the vapors, that were able to penetrate the sediments without fissuring, scatter sphalerite and galena as widely as garnet, pyroxene, etc.? Mr. Umpleby explains the localization of the ore sulphides as due to the selectiye action of the biotite schist. However, near the surface, much more ore was in the micaceous quartzite than in the biotite schist, on the 300-foot level, as may be seen from his sketch, fully one half of the ore was not in the biotite schist, and on lower levels progressively more of the ore was in the biotite schist because the monzonite was encroaching upon and cutting away the west segment of the main vein and the South spur. I have examined over one hundred contact metamorphic ore deposits, distributed in about a score of districts in Idaho, California, Nevada, Utah and Arizona, and I have seen many cases of selective action, but this Success deposit, so far as the ore is concerned, does not seem to me to even remotely approach the type. The only selective action that I can see was that of a system of fissuring and shearing that largely cut the banding of the schist and the quartzites. It is not to be supposed that vapors carrying the constituents of the ore sulphides and partial constituents of the contact silicates replaced the quartzites and schists with sphalerite, galena and contact silicates only adjacent to the fissures and deposited contact silicates alone throughout the tongue of Prichard rocks. I am aware that in most contact metamorphic ore deposits the sulphides are not uniformly distributed through the masses of contact silicates, but we have here something different from a

mere erratic scattering of sulphides. The widely distributed contact silicates are part of the country rock and should not be appended to the definite sphalerite- and galena-bearing zones to destroy the vein-like character of the latter and make a supposedly typical large irregular contact metamorphic ore deposit. Similarly, the widely scattered pyrite in the altered monzonite should not be added to the ore-bearing zones to destroy the latter as veins of zinc and lead ores. The sphalerite and galena are peculiarly localized, which now requires an explanation.

There is nothing in Mr. Umpleby's discoveries with the microscope that is incompatible with the following history of the deposit: (1) The sediments were metamorphosed to schist, micaceous quartzites and dense quartzite; (2) the schist and quartzites were faulted and fissured; (3) sphalerite and galena were deposited largely by replacement in the fractured zones; (4) the monzonite was intruded; (5) contact silicates were widely deposited as the result of gases or water emanating from the magma. This may have been partly contemporary with the intrusion but continued afterwards. The vapors searched out the sphalerite- and galena-bearing zones and partly reworked the deposits, causing the sulphides to partly migrate distances measurable in inches rather than feet, and redeposited them with contact silicates. This perfectly explains why the sphalerite and galena are where they are and not widely distributed with the contact silicates and with the pyrite and sericite in the monzonite. It explains why, in a few places in the lead- and zinc-bearing zones, ore sulphides occur in aplite dikes, but do not occur in aplite dikes beyond these definite zones. The idea of limited migration under metamorphic action may be the key to the problem. At any rate, there remains in my mind a feeling of uncertainty that Mr. Umpleby has proved that the zinc and lead salts came out of the monzonite magma after the intrusion as we see its products in the mine, and the writer hopes that he will continue the discussion so that different points of view may be adjusted and some incontrovertible evidence of the true origin of the ore minerals discovered.

OSCAR H. HERSHEY.

REVIEWS

Elements of Mineralogy, Crystallography, and Blowpipe Analysis from a Practical Standpoint. By ALFRED J. MOSES AND CHARLES L. PARSONS. Fifth Edition. Enlarged and in large part rewritten. New York, D. Van Nostrand Company, 1916. Pages 631. Figures 575. Price $3.00.

The increase of nearly 200 pages over the fourth edition (1909) testifies to the enlarged character of this latest edition of Moses and Parsons' well-known "Elements." This increase has been not merely inserted into the book at a certain place, but has been well distributed throughout, thus retaining the balance of the different parts. One finds old minerals, which have become of economic value, such as fergusonite, gadolinite, samarskite, roscoelite, variscite, and others, as well as such new minerals of economic value as baddeleyite, patronite, hewettite, uvanite, thorianite, and benitoite, added to the list. The new material has been so judiciously introduced, and the book brought so thoroughly up to date, that it almost seems like a new text instead of a new edition of a work first published in 1895. The practical point of view has been consistently maintained, and the chapters on crystallography clearly state the subdivisions, based on symmetry, into which crystals are classified, without troubling the reader with long names or abstruse mathematics.

The minerals are grouped as: *Minerals of the Metalliferous Ore Deposits, Minerals Important in the Industries and Not Already Described,* and *Silica and the Rock-forming Silicates.* The metalliferous minerals are grouped according to their metallic base, thus the iron minerals, the copper minerals, etc., are described together. The useful minerals are grouped according to the useful element in their composition, as the potassium minerals, the calcium minerals, the boron minerals, the phosphorous minerals, etc. The rock-forming silicates follow the usual grouping, such as feldspars, micas, etc. Preceding the mineral descriptions is a chapter which sums up the *Formation and Occurrence of Minerals;* following it is a chapter on *Minerals Used as Precious and Ornamental Stones.* In order to avoid repetition, the mineral description is given in full in only one place but needed cross references are sometimes omitted. Thus under *The Carbon Minerals* (p. 472) there is no men-

tion of the diamond, which is described under *Minerals Used as Precious and Ornamental Stones.*

In the mineral descriptions, the "practical standpoint" is emphasized by such paragraphs as *Economic Importance* with statistics of production and uses, and *Formation and Occurrence,* which precede the descriptions of the individual minerals. The precious stones, which form the subject of a new chapter, are divided into transparent stones and translucent to opaque stones. The information given in this chapter, with references to the other parts of the book, serves to make the work of value to jewelers and to others specially interested in gems.

An innovation in the Tables for Rapid Determination of the Common Minerals consists in the identification of minute crush fragments by using the microscope to determine the indices of refraction, the birefringence, and other optical properties.

W. T. SCHALLER.

SCIENTIFIC NOTES AND NEWS[1]

PROFESSOR WALDEMAR LINDGREN, of the Massachusetts Institute of Technology, has gone to Idaho for a few weeks.

BURTON HARTLEY, of the Cosden Oil and Gas Co., has entered the Officers' Training Camp at Leon Springs.

E. K. SOPER, formerly of the University of Idaho, has been appointed dean at the Oregon State School of Mines.

E. S. MOORE, professor of geology at Pennsylvania State College, spent the last field season in oil work in Cuba.

PROFESSOR J. F. KEMP, of Columbia University, has become associated temporarily with the firm of Hager, Bates and Lewis, of Tulsa, Okla., during the absence of Whitney Lewis in France.

H. E. GREGORY has gone to the Hawaiian Islands for a few months, to carry on some geological investigations.

JOSEPH BARRELL has gone to Idaho on professional business.

A. M. BATEMAN has returned from Alaska, where he has been doing consulting work for the Kennecott Copper Corporation.

FREDERICK G. CLAPP, of the Associated Geological Engineers, has been in Kansas and Oklahoma recently.

D. W. BRUNTON, of Denver, is spending a few weeks in New York.

J. B. TYRELL has been to Newfoundland.

[1] Geologists, mining engineers and others interested in applied geology are invited to keep the editor informed of new investigations of mining districts or scientific studies undertaken by them, together with such other scientific and personal items as may come to their notice.

ERRATA.

Vol. 12, No. 5.

Page 393, line 9, for "varying width" read varying in width.

Page 397, bottom of page, for "mine have been" read mine they have been.

Page 397, bottom of page, for "pipe-line" read pipe-like.

Page 403, bottom, last sentence should be in large print.

Page 404, line 14, for "to be a less extent" read to be to a less extent.

Page 411, line 4, for "of" read or.

Page 411, line 11, no sentence.

Page 420, last line, for "page 22" read page 411.

Page 426, line 18, for "pyrrhotite, norite" read pyrrhotite-norite.